Geologic Resource Evaluation Scoping Summary
Gulf Islands National Seashore

Geologic Resources Division
National Park Service
U.S. Department of the Interior

The Geologic Resource Evaluation (GRE) Program, administered by the NPS Geologic Resources Division, conducts scoping for each of the identified 270 natural-area National Park System units. The National Park Service held a GRE scoping meeting for Gulf Islands National Seashore on September 12–15, 2006. In general, the purpose of scoping is to identify (1) geologic mapping coverage and needs, (2) distinctive geologic processes and features, (3) resource management issues related to geology, and (4) potential monitoring and research needs. During scoping, participants evaluate the adequacy of existing geologic maps for resource management, discuss geologically related management issues with subject experts, and when possible take a field trip with local experts. Outcomes of the scoping process are a scoping summary (this document), a digital geologic map, and a geologic resource evaluation (GRE) report, which accompanies the map. Typically, GRE scoping summaries are relatively short documents. By contrast, this “summary” is lengthy with the intent of providing staff at Gulf Island National Seashore (GUIS) with information for their upcoming general management plan (GMP) process. Like other scoping summaries, however, this summary will serve as a starting point for the GRE report once mapping is completed. Information gained from future field mapping and modeling will enhance the current “Geologic Resource Management Issues,” “Geologic Features,” and “Geologic Processes” sections of this scoping summary for the GRE report. The report will also contain a map unit properties table, which links the geologic map with geologic features, process, and issues.

Superintendent Jerry Eubanks welcomed the participants to the scoping meeting, and Chief of Science and Resources Management Rick Clark highlighted some of the issues facing park staff for which geologic information would be beneficial: hurricanes, groundwater discharge, sea-grass habitat, and oil and gas leasing in the vicinity of the national seashore. Staff members from the NPS Geologic Resources Division in Lakewood, Colorado, facilitated the discussion of mapping needs, which incorporated identification of some features, processes, and issues. In addition, Jim Flocks (U.S. Geological Survey) presented information about coastal and marine projects relevant to the Gulf of Mexico. Chris Houser (University of West Florida) presented information about the role of the “geologic framework” at Gulf Islands National Seashore. Chris Blount (Georgia Institute of Technology–Savannah) presented information about a storm-surge survey and damage assessment of the Gulf Coast after Hurricane Katrina. John Baehr (U.S. Army Corps of Engineers) provided information and answered questions about the Mississippi Coastal Improvement Project. Other participants at the meeting included NPS personnel from the national seashore, Gulf Coast Network, and Southeast Regional Office, as well as cooperators from the Florida Geological Survey, Mississippi Department of Environmental Quality, University of West Florida, Colorado State University, Kent State University, and the Gulf Coast Geospatial Center (see table 1).

Table 1. Scoping Meeting Participants

Name	Affiliation	Title	Telephone	E-mail
John Baehr	U.S. Army Corps of Engineers	Land geologist	251-690-3146	john.n.baehr@usace.army.mil
Rebecca Beavers	NPS-GRD	Coastal geologist	303-987-6945	rebecca_beavers@nps.gov
Chris Blount	Georgia Institute of Technology–Savannah	Graduate research assistant (fluid mechanics)	912-293-7135	gtg882y@mail.gatech.edu
[1]Julia Brunner	NPS-GRD	Policy and regulatory specialist	303-969-2012	julia_f_brunner@nps.gov
Greg Carter	University of Southern Mississippi–Gulf Coast Geospatial Center	Chief scientist	228-818-8868	greg.carter@usm.edu
Rick Clark	NPS-GUIS	Chief of science and resources management	850-916-3011	rick_clark@nps.gov
Tim Connors	NPS-GRD	Geologist	303-969-2093	tim_connors@nps.gov
Sid Covington	NPS-GRD	Geologist	303-969-2154	sid_covington@nps.gov
Monette Dalal	Kent State University	MS student (geology)	330-672-3240	mdalal@kent.edu
Jim Flocks	USGS	Coastal geologist	727-803-8747	jflocks@usgs.gov
Ron Hoenstine	Florida Geological Survey	Director (coastal research)	850-488-8747 x. 9308	ron.hoenstine@dep.state.fl.us
Riley Hoggard	NPS-GUIS	National resource specialist	850-934-2617	riley_hoggard@nps.gov
Gary Hopkins	NPS-GUIS	Biologist	228-875-9057 x.104	gary_hopkins@nps.gov
Chris Houser	University of West Florida	Assistant professor (coastal geomorphology)	850-857-6121	chouser@uwf.edu
Katie KellerLynn	Colorado State University	Research associate/geologist	801-608-7114	katiekellerlynn@msn.com
Klaus Meyer-Arendt	University of West Florida	Professor and department chair	850-474-2792	kjma@uwf.edu
Andrew Moore	Kent State University	Assistant professor (geology)	330-672-9465	amoore5@kent.edu
Mark Nicholas	NPS-GUIS	Biologist	850-934-2119	mark_nicholas@nps.gov
[1]Lisa Norby	NPS-GRD	Geologist	303-969-2318	lisa_norby@nps.gov
[1]Ervin Otvos	University of Southern Mississippi	Professor Emeritus	228-388-7200	otvos@cableone.net
Martha Segura	NPS–Gulf Coast Network	Network coordinator	337-291-2113	martha_segura@nps.gov
Barbara Yassin	Mississippi Department of Environmental Quality	GIS specialist	601-961-5571	barbara_yassin@deq.state.ms.us
Linda York	NPS–Southeast Regional Office	Coastal geomorphologist	404-562-3113 x. 537	linda_york@nps.gov

[1]Report contributor/reviewer only.

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Park Setting

Authorized January 8, 1971, Gulf Islands National Seashore preserves both natural and cultural resources along the Gulf of Mexico in Florida and Mississippi. The barrier islands in the Florida portion of the national seashore are Santa Rosa and Perdido Key (fig. 1). Most of Santa Rosa Island is very narrow (only few hundred meters wide) but hosts a continuous beach that extends nearly 52 miles (84 km). The island is nearly parallel to the mainland coast between Destin and Pensacola. Behind the island is Santa Rosa Sound, a continuous lagoon tapering in width from 2 miles (3.2 km) near the western end to less than 0.25 mile (0.4 km) eastward. Passes connect this lagoon to bays at both ends.

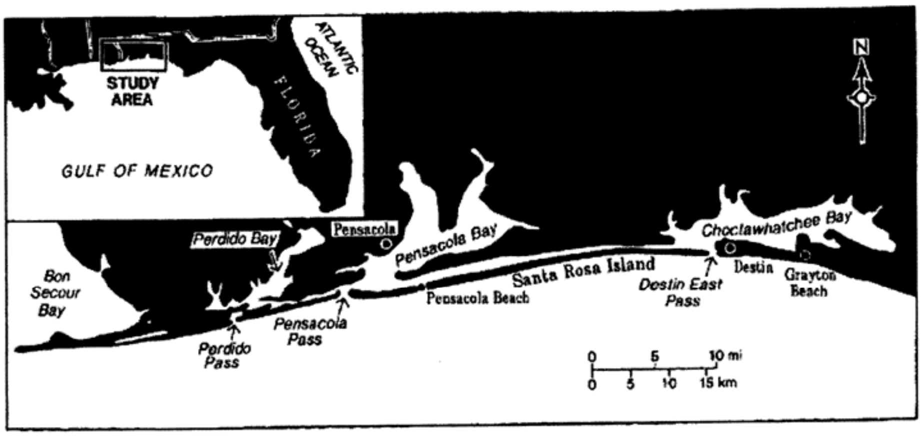

Figure 1. Index Map of Florida Barrier Islands and Vicinity. *Source*: Stone and Morgan (1993).

In Mississippi, the islands in the national seashore are Petit Bois, Horn, East Ship, and West Ship, and a portion of Cat Island (fig. 2). A total of six barrier islands along the Mississippi Sound parallel the mainland coast. In Alabama, Dauphin Island lies at the mouth of Mobile Bay; it is the only member of this island chain that is not part of the national seashore. The Mississippi Sound landward of the islands is a wide lagoon, more than 7 miles (11 km) on average. It deepens gradually from the mainland shore to the islands, with depths exceeding 20 feet (6.1 m) at the passes (Kwon, 1969). The national seashore also includes mainland tracts of Naval Live Oaks near Pensacola, Florida, and the Davis Bayou area at Ocean Springs, Mississippi.

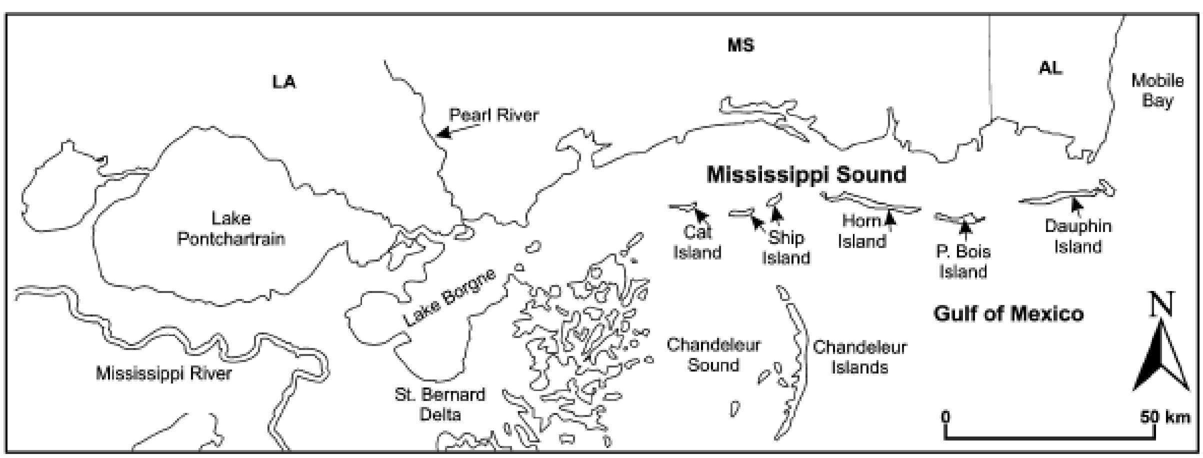

Figure 2. Index Map of the Mississippi–Alabama Barrier Island Chain. *Source*: Otvos and Giardino (2004).

At more than 100 miles (160 km) in length, Gulf Islands National Seashore is the longest national seashore in the United States. More than 80% of its resources and land area are submerged. The national seashore also preserves extensive cultural resources, including a system of coastal fortifications dating back to the late 19th century. Its beaches, which provide recreational access to the Gulf of Mexico, are composed primarily of medium-grained, white quartz sand. However, several important heavy minerals comprise a small percentage of the sand (Foxworth et al., 1962); for instance, local concentrations of titanium-bearing heavy minerals on Ship Island prompted a Bureau of Mines study to investigate their economic potential after Word War II (Ervin Otvos, University of Southern Mississippi, written communication, February 4, 2007).

Geologic History

Table 2. Stratigraphy of Gulf Islands National Seashore

Age	Deposit	Setting
Late Holocene	Recent marine, beach, and dune sands	Mainland shore, barrier island, inlet, shoal platform, and tidal delta
	Nearshore marine and brackish inshore sands and muds	Brackish lagoon, bay, salt-brackish marshes, swamps, and river delta
Late Pleistocene	Eolian sand sheets and dunes (Wisconsin stage)	Well inland of contemporary low sea levels
	Gulfport Formation	Shallow nearshore, beach and dune environments
	Biloxi Formation	Nearshore marine and estuarine environments
	Prairie Formation	Floodplain
Pliocene	Citronelle Formation	River floodplain with minor estuarine components
	“Graham Ferry Formation” in Mississippi and Alabama	Fluvial, estuarine, and nearshore marine (undifferentiated)
Late Miocene	“Pascagoula Formation” in Mississippi and Alabama	Fluvial, estuarine, and nearshore marine (undifferentiated)

Santa Rosa Island

The general scientific consensus for the evolution of Santa Rosa Island is that the barrier island emerged from an elongated shoal 4,000–3,500 years ago and has apparently kept pace with slowly rising sea level since then (Otvos, 2005a, b). This late Holocene, sandy nearshore shoal was attached to a “Pleistocene core” around which the island’s eastern and western shoal platform may have subsequently developed. The narrow Pleistocene core, located under the middle sector of Santa Rosa Island, probably consisted of barrier ridge sands of the Gulfport Formation (table 2). In the subsurface, younger Holocene nearshore sands veneer the late Pleistocene deposits of the Gulfport Formation and the underlying Biloxi Formation; recent beach and dune sands make up the surficial deposits. The “composite nature” of Santa Rosa Island with its Pleistocene “core” and Holocene “veneer” facilitated stabilization and further longshore propagation of the island (Otvos, 1982a). Holocene Santa Rosa Island lies in continuation of and receives littoral drift from the late Pleistocene Destin headland east of Destin East Pass (see fig. 1). Nearly the entire island periodically undergoes extensive overwash during hurricanes.

Landward of Santa Rosa Island, the coastal plain surface is underlain by a wide belt of mostly fluvial, late Pliocene sediments of the Citronelle Formation (table 2). At several northwestern Florida and southeastern Alabama locations, Citronelle deposits include inter-layered estuarine lenses (Otvos, 1997, 2005d). Sediment cores revealed no readily recognizable Citronelle Formation deposits beneath Santa Rosa Island itself, however. The stratigraphic units that underlie Santa Rosa Island include alluvial and brackish, locally marine sands and muds, which are part of a thick late Miocene to early Pliocene sediment sequence. Earlier publications referred to these sediments as the “Pascagoula” and overlying “Graham Ferry” formations in Mississippi and Alabama. However, these terms are probably obsolete because the formation boundaries are still not well established in the subsurface (Otvos, 1994, 1997; Ervin Otvos, University of Southern Mississippi, written communication, February 28, 2007).

When sea level was lower and climate was drier during the late Pleistocene Wisconsin glacial stage, eolian processes formed dunes and sand sheets from reworked sands of older (perhaps Gulfport Formation) deposits. These dunes and sand sheets cover the Gulfport Formation in the adjacent Florida and southeastern Alabama mainland areas, including the headquarters area of Gulf Islands National Seashore at Gulf Breeze, Florida (Otvos, 2004a).

Mississippi–Alabama Barrier Islands

The Mississippi–Alabama barrier chain is underlain by the same Miocene to late Pleistocene sedimentary sequence as under Santa Rosa Island. As in Florida, the barrier islands in Mississippi formed from shoals (Otvos, 1979, 1997, 2005c) though earlier (5,700–5,000 years ago) when sea level was lower than present by approximately 3 to 5 feet (1.0–1.5 m) (Otvos and Giardino, 2004; Otvos, 2005a, c, d). The Mississippi–Alabama island chain formed against a background of decelerating sea-level rise during the late Holocene. At this time, eastern Dauphin Island represented an isolated “high ground” and in continuation with the huge Mobile Pass ebb-tidal delta became the pathway for westward transmission of extensive volumes of littoral sand. Drill holes encountered the Biloxi Formation and probably also the Prairie formations under the barrier islands. These units also occur beneath the adjacent Mississippi, Alabama, and northwestern Florida mainland coastal plain. The high eastern Dauphin Island sector is underlain by a Pleistocene core composed of barrier ridge sands of the Gulfport Formation, which are underlain by the Biloxi Formation (Otvos, 1982a, 1982b; Otvos and Giardino, 2004). Late Holocene nearshore marine sands surround this core. Recent beach and dune deposits top the sequence.

Eastern Dauphin Island captured and forwarded large volumes of sand from the Mobile Bay ebb-tidal currents and from the mainland shores of northwestern Florida and southeastern Alabama via westward-directed littoral drift. Isolating a lagoon of the newly established Mississippi Sound, the Alabama–Louisiana island chain thus emerged. It aggraded on a series of long, shallow shoal platforms that accumulated parallel to the mainland over muddy, nearshore marine late Holocene sediments (Otvos, 1979; Otvos and Giardino, 2004).

Between 4,000 and 3,500 years ago, a lobe of the St. Bernard delta of the Mississippi River (see fig. 2) prograded into the area west of the Mississippi barrier islands. Delta progradation resulted in mainland extension, shoaling, and marsh development. As a result, the western Mississippi and southeastern Louisiana members of the barrier-island chain west of Cat Island became stranded, that is, deactivated in the emerging marshlands. By about 2,400 years ago, the sediments from a prograding and greatly expanding younger St. Bernard delta lobe created shoals as far west as Ship Island. Diminishing the impact of the Gulf wave regime, these shoals had interrupted westward-directed littoral drift, and Cat Island became deactivated by shoal development. With the sand supply from the islands in the east cut off, the eastern end of Cat Island started to erode. At the same time, shore erosion, combined with continuing tectonic subsidence in the adjacent eastern marginal zone of the Holocene Mississippi delta complex, had eliminated the oldest ridge sets in northern Cat Island (Otvos, 1979; Otvos and Giardino, 2004).

With the exception of Cat Island, where the influence of delta subsidence has been impacting that island, the barriers in the Mississippi–Alabama island chain kept pace with rising sea level during the Holocene. Nevertheless, the erosive history and rate of area losses of the island chain may suggest a relatively short life expectancy for at least some of the barrier islands, for example East Ship (Otvos and Giardino, 2004; Otvos and Carter, 2007). Episodic hurricane destruction and island segmentation has played an essential role in the evolution of all the Mississippi–Alabama barrier islands (Otvos, 1979) and will continue to do so (see "Hurricane-Generated Features" section). At its peak, Hurricane Katrina (2005) completely submerged the entire barrier island chain, segmenting several islands and reducing their size.

French and British charts from the 18th century indicate that Dauphin and Petit Bois islands once formed a single entity (Isle Dauphin) (Otvos, 1979). The oldest (eastern) part of Petit Bois Island formed the western sector of Dauphin Island at that time. After Petit Bois and Dauphin islands became separated, Petit Bois lost most of its long, narrow eastern sector apparently during a single (1916) major hurricane event (Otvos and Carter, 2007). Widening to a record 5.3 miles (8.5 km) by 1957, Petit Bois Pass now partially overlaps the former Dauphin Island area. Since the 1850s, Petit Bois has prograded westward in downdrift direction (Otvos, 1979). While the island advanced approximately 3.1 miles (5.0 km) westward between 1850 and 1974, its 9.6-mile- (15.5 km) long eastern sector reverted to a shoal platform.

Another example of periodic erosion and aggradation is the Isle of Caprice, which was part of the Dog Keys. Isle of Caprice existed intermittently between Horn and Ship islands from 1848 to 1940 and was probably cut in two by a hurricane in July 1916 (Otvos, 1979). Ship Island has been repeatedly split into West Ship and East Ship islands since the mid-19th century, for instance, during a cyclone event (1947) and Hurricanes Betsy (1965) and Camille (1969) (Falls, 2001; Otvos and Carter, 2007). Chart and survey data document a reduction in area of Ship, Horn, and Petit Bois islands by 26% in 150 years, declining from a combined surface area of 15.5 square miles (40.2 km^2) in 1850 to 11.5 square miles (29.7 km^2) in 2000 (Otvos and Giardino, 2004).

Geologic Features

In a setting composed of sand and water, the geologic features of Gulf Islands National Seashore are transient. Natural interactions among relative sea level, sediment supply, and meteorological-oceanographic conditions, and human-induced changes from dredging, sediment diversion, and habitat modification resulted in the present configuration (Schmid, 2003). The islands overlie earlier alluvial and estuarine stratigraphic units and are constantly being modified by erosional, aggradational, and progradational processes (Otvos, 2005a, b, c). In spite of their transience, however, at any given time the barrier islands host a myriad of distinctive features that underscore habitats and provide visitor enjoyment.

Beaches and Dunes

Breaking waves deposit sand, creating beaches, and the wind either moves the sand inland as sand sheets or dunes or back out to sea. Vegetation is critical in dune building and stabilization. Sea oats and other dune plants equipped with elaborate stem and root systems play a vital role in holding the sand in place. Without the development of dunes, sand accretion can proceed only as high as the storm surge can reach. The foredune line, or primary dunes, are first-line defenses from storms and will usually be the highest in elevation (Falls, 2001). The height of the dune is controlled primarily by grain size and wind velocity, whereas seaward dune vegetation growth is controlled by wave action and soil salinity. The seaward dune position also depends upon the frequency of storms eroding the dune face and the rate at which these scarps can heal by wind transport and vegetation growth (Leatherman, 1988). On eroding shorelines, dune system survival depends upon the relative rates of dune migration and shoreline retreat (see "Restoring Dunes" section). Dunes may be eroded and breached during periods of increased shoreline erosion (Leatherman, 1988).

Beaches initially dissipate wave energy during the early stages of storm events as storms approach. Consequently, beach width can influence the impacts of storms depending on storm intensity and duration. In general, wide beaches provide more protection than narrow beaches. In most coastal areas, natural stable beaches are usually more than 100 feet (30 m) wide. Based on this observation, the USGS coastal classification system defines beach width as either greater than or less than 100 feet (30 m). The beach width category is perhaps the most subject to change of all the USGS classifications because beaches are naturally dynamic, and their widths can be altered by human activities (see http://coastal.er.usgs.gov/coastal-classification/class.html [accessed December 18, 2006]).

Santa Rosa Island is flanked by steep beaches on the Gulf of Mexico side (5% slope) and gently sloping beaches on the Santa Rosa Sound side. The sand is medium grained (defined as between 0.60 millimeters and 0.43 millimeters in median diameter) with very good sorting, resulting in an even grain size with only a small fraction of fine (e.g., silt) and course (e.g., pebbles or shell hash) grains. At wider sections of the island, longitudinal dunes align with the dominant summer winds. These dunes serve a number of functions including protection from wind and salt spray.

The Mississippi Sound barrier islands are characterized by four environments: interior dunes, coastal marshes, interior brackish ponds and creeks, and interior sand flats. The ocean beaches, which face higher energy waves, are much wider and better developed than those that face the Mississippi Sound. The majority of the dunes are less than 13 feet (4 m) high, but some relict beach ridges, representing previous island growth stages, on Horn Island reach 26 feet (8 m) (Ervin Otvos, University of Southern Mississippi, written communication, February 26, 2007).

The Mississippi islands' foreshore and nearshore deposits are well- to very well–sorted, fine- and medium-grained sand (medians commonly between 0.25 and 0.49 mm) (Otvos, 1973). The average grain size is coarser on the lower energy (north) side of most of the islands due to the differential transportation of the fine fraction (Otvos, 1975). The shoal platform areas located between the islands are composed of well- and very well–sorted medium sands (Otvos, 1973).

Hurricane-Generated Features

Monette Dalal (MS student, Kent State University), a participant at the scoping meeting, investigated the sedimentary structures deposited as a result of Hurricane Katrina. Dalal presented "Sedimentation from 2005 Hurricane Katrina on the Mississippi and Alabama Gulf Coast Barrier Islands" at the Geological Society of America (GSA) annual meeting in October 2006. These findings show that sedimentary structures deposited during the storm record the temporal acceleration of the storm (i.e., the velocities of the surge current).

The eye of Hurricane Katrina passed west of the east-west trending island chain in the northern Gulf of Mexico. Field research on storm-parallel transects of hurricane deposits extended laterally from the western end (Cat Island) to the eastern end (Dauphin Island) of the chain (see fig. 2). Within these transects, massive sediment deposits on the beach terminate along thin washover fans, approximately 500–650 feet (150–200 m) from the shoreline. The storms also widened the gap between East Ship and West Ship islands and, helped by inter-ridge swales conducting storm waters to the island interior, reduced East Ship to a small fraction of its pre-storm area (Otvos and Carter, 2007).

Sediment thickness in washover fans ranges from 8 to 30 inches (20 to 80 cm). The deposits are composed of moderately well to well-sorted, medium- to coarse-grained sand, mostly subrounded quartz grains, with local concentrations of magnetite. The sand often has an erosive base, and may fine upward and landward, although the limited range of grain sizes available on the beach makes this trend difficult to verify (Monette Dalal, Kent State University, draft GSA abstract, September 15, 2006).

Bent grasses and broken trees in the direction of flow and tree scouring demonstrates that flow depth was at least 25 feet (8 m) above the base of East Ship Island, and 13 feet (4 m) above baseline on Horn Island. Erosion occurred at both the eastern and western tips of the islands, instead of the more typical selective erosion on one end and deposition on the other (Monette Dalal, Kent State University, draft GSA abstract, September 15, 2006).

Inlets and Lagoons

The lagoons or bays that lie between the barrier islands and the mainland communicate with the water of the open shelf by tidal flow, which is directed through a network of inlets. Inlets are also the primary means by which sand is transported landward across a migrating barrier system. Inlets act as complete or partial barriers to nearshore sediment transport. Depending on the strength of the nearshore current vs. the tidal jet flushing capacity, an inlet may trap sand or naturally bypass a large portion of the sediment in the littoral drift system. Under the conditions of small tidal flows and high rates of littoral drift, an inlet will eventually close (Leatherman, 1988). Inlets along microtidal coasts, such as the Gulf barrier islands, tend to close unless substantial outflow from a major river interferes. Dredging is often necessary in order to maintain a navigable channel through a barrier island (see “Dredging and Beach Nourishment” section). Attempts to stabilize inlet channels by jetties have often led to severe erosion and deposition of adjacent shores, and continued dredging operations are usually necessary (Leatherman, 1988).

Paleontological Resources

The National Park Service has not completed a formal paleontological resource survey for Gulf Islands National Seashore. However, a draft paleontological resource inventory was completed in September 2006 (Jason Kenworthy, NPS paleontologist, e-mail communication, September 27, 2006). Perhaps most significantly, the subsurface fossils found at Gulf Islands National Seashore offer scientific, educational, and interpretive opportunities related to barrier island formation and the evolution of the Gulf of Mexico. According to Otvos and Giardino (2004), “A wealth of new data provides a well-constrained chronology of mid- to late Holocene coastal development in the Louisiana-Mississippi borderland that may also be utilized in a globally applicable sedimentation model.” Investigators obtained these data from a closely sampled network of rotary core holes in the Mississippi–Alabama barrier islands and the Mississippi Sound. They include microfossil and archaeological materials (Otvos, 1981, 1997; Otvos and Giardino, 2004)

Table 3. Paleontological Resources at Gulf Islands National Seashore

Location	Age	Fossils
Horn Island	Holocene	Microfossils, echinoid spines, fragmented mollusks, limonitized molluscan molds
	Late Pleistocene	Foraminifera and other microfossils, ostracodes, mollusks (pelecypods bivalves), dinoflagellates, pollen
Santa Rosa Island	Late Pleistocene	Foraminifera, mollusks
Davis Bayou	Pleistocene	Foraminifera, mollusks, ostracodes

Sources: Brown et al. (1944), Walton (1960), Marsh (1966), Otvos (1981) (1982a) (1988), Gohn et al. (1996).

In contrast with Padre Island National Seashore (Texas), Gulf Islands National Seashore does not have an offshore source of paleontological material. Therefore, very few fossils wash onto the shores at Gulf Islands National Seashore. However, the national seashore’s collection contains one potentially paleontological specimen, which curators hold at the NPS Southeast Archeology Center. The specimen is described as a mineralized fossil and may be a mollusk shell (Riley Hoggard, GUIS, personal communication to Jason Kenworthy, NPS paleontologist, 2006). The material apparently was found in association with an archaeological site. The actual age and identification of the specimen is unknown.

An abundance of microfossils in the Gulf Islands National Seashore area occur in Holocene and older subsurface deposits. Drilling has revealed paleontological resources on Horn Island, Santa Rosa Island, and the Davis Bayou area (table 3). While no fossils have yet been found exposed at the surface near Naval Live Oaks or Fort Barrancas, drilling west of the Naval Live Oaks area recovered late Pleistocene mollusks from a depth of approximately 25 feet (8 m) in a well located on “Fairpoint Peninsula.” In addition, rare Holocene and Pleistocene molds and casts—formed by secondary limonite and humate replacement of nearshore and estuarine molluscan shells and foraminifers—occur in situ and reworked in the Mississippi islands and mainland area (Otvos, 1982a, 1997; Ervin Otvos, University of Southern Mississippi, personal communication, 2007).

Submerged Features

Submerged features on the inner shelf modify waves and currents and thereby affect patterns of sediment erosion, transport, and deposition on the adjacent shoreface. Such features are part of the "geologic framework" (see "Geologic Mapping for Gulf Islands National Seashore") and include buried channels, hard bottoms, and shoals. Mapping of the geologic framework will provide information about these resources for the final geologic resource evaluation report.

In addition, a valued submerged resource at Gulf Islands National Seashore is sea-grass beds. Sea grasses form the basis of the food web in clear water systems and provide important nursery habitat for many species. Though not a geologic resource, sea grass stabilizes bottom sediments and improves water clarity by trapping fine particles that would otherwise remain suspended by wave and current action. Sea grasses bind shallow water sediments with their roots and rhizomes, and baffle wave and current energy with their leafy canopy (Kenney, 2006). Sea-grass habitat (table 4) within the national seashore consists of shallow areas less than 7 feet (2.1 m) deep with stable sediments and slow currents.

Table 4. Sea-Grass Habitat in Gulf Islands National Seashore

Location	Acres (hectares)
Big Lagoon (Perdido Key area)	640 (259)
Fort Pickens	422 (171)
Santa Rosa area	772 (312)
Naval Live Oaks	94 (38)
Florida district (subtotal)	1,928 (780)
Ship Island (East and West)	1,104 (447)
Horn Island (including Spoil Island)	1,458 (590)
Petit Bois Island	729 (295)
Mississippi district (subtotal)	3,291 (1,332)
Total for national seashore	**5,219 (2,112)**

Source: Kenney (2006).

Washover Fans

Fan-like deposits of sand called "washover fans" occur where large ocean waves overtop the low-lying parts of a barrier island and input beach and dune sand into the backshore zone through a process called overwash (see "Overwash" section). Though usually occurring during a storm, overwash may occur during marginal events in low areas, particularly if the breaking waves coincide with high spring tide. According to Chris Houser's presentation during the scoping meeting, the amount of overwash along the barrier islands depends on the spatial distribution of dunes. Where low dunes exist, overwash occurs. Moreover, breaches generally occur in recurring patterns. Where large dunes exist near the shore, overwash is less likely to occur. Secondary dunes are farther from the active beach processes, except during storms, and can result in offshore transport of sediment. Nevertheless, overwash during surges of major hurricanes (e.g., Ivan, Frederic, and Katrina) penetrated several hundred meters and reached the island centers and the sound shores, overwhelming and locally destroying tall foredunes (Otvos and Carter, 2007). The tallest dunes in the interior of West Ship Island, for example, may have stopped overwash. Also, in wider island sectors, as in elevated parts of Horn Island, the tall relict sand ridges of the island interiors provided barrier to overwash (Ervin Otvos, University of Southern Mississippi, written communication, February 4, 2007).

According to Leatherman (1988), overwash generally occurs where the dune system has been weakened either naturally by blowouts or artificially by human activity (see "Development and Other Human Impacts" section). Depressions in the ridge front, especially vehicle crossovers, serve as passages for flood waters during storms. Overwash surges through these breaches and excavates the dune base by lateral undercutting. In this fashion, the washovers will become larger at the expense of barrier dunes.

Wetlands and Ponds

Wetlands at Gulf Island National Seashore include salt marshes, tidal flats, and freshwater wetlands. Salt marshes are located in the protected waters of all the offshore islands and several of the mainland sections of the national seashore. According to Anderson et al. (2005), salt marshes cover an area of 554 acres (224 ha) on Petit Bois Island, 594 acres (240 ha) on Horn Island, 258 acres (104 ha) on East Ship and West Ship islands, and 300 acres (121 ha) on Santa Rosa Island.

Salt marsh areas are flat, poorly drained, and subject to periodic overflow by salt water; hence, their waters are strongly saline or brackish. Salt marshes on barrier islands build upward through time via the deposition of highly productive organic peat; this allows salt marshes to maintain their relative elevation in concert with rising sea level (Leatherman, 1988). Because of the cohesive nature of peat deposits, salt marshes are very resistant to erosion, even when subjected to storm-generated currents and breaking waves. With continuous wave action, however, older marshes behind barriers in a large bay can be slowly eroded by bank collapse (Leatherman, 1988). Tidal flats or marshes form in areas of low wave energy bordering the coast such as shallow lagoons or sheltered bays. High tides regularly inundate these areas, which consist of mud and a resistant mat of roots of salt-tolerant plants. An extensive tidal marsh is located in the Davis Bayou area of the national seashore. Intertidal flats are located between the high- and low-tide water levels of estuaries, bays, lagoons, and river mouths (Anderson et al., 2005). Freshwater wetlands are characterized by no salinity and are generally not tidally influenced. On barrier islands, precipitation is the only source to maintain areas with standing water and the groundwater table.

Freshwater ponds are small and controlled by the level of groundwater beneath the dunes. Leatherman (1988) classifies ponds into two basic groups: (1) dune ponds in low areas (slacks and swales) between sand dunes, and (2) coastal ponds created by the closing of a former bay or lagoon. The ponds located within Gulf Islands National Seashore have varying salinities depending on their primary water source (e.g., rainfall, groundwater, or inflow from bays). Snyder et al. (1997) investigates the salinity of the ponds on Santa Rosa Island after Hurricane Opal (1995). The authors noted that at that time, the Fort Pickens area contained four major water bodies, numerous smaller ponds, permanent wetlands, and temporary wetlands in dune blowouts (swales). All ponds tested were brackish with salinities ranging from 0 to 30 parts per thousand (ppt) (Snyder et al., 1997). During the study period, the salinity of the Gulf of Mexico ranged from 27 to 36 ppt, and the salinity of the groundwater was recorded at 0 ppt (Snyder et al., 1997).

Geologic Processes

Barrier island morphology is very changeable: beaches erode and accrete; dunes shift positions; washover fans are periodically active; inlets open, migrate, and close. The long-term behavior of a barrier island depends principally upon sand supply, the rate of sea-level rise, and sea energy. Human intervention can also be a significant factor. After investigators map the geologic framework and surficial geology (see “Mapping for Gulf Islands National Seashore”), modeling of the past and future evolution of the barrier island system will help determine the response of these islands to future sea-level rise and storm surges.

Barrier Island Evolution

Two models of island evolution are displayed at Gulf Islands National Seashore and adjacent areas: regressive (seaward building) and transgressive (landward retreating). In both models, sand supply is the key to a barrier island’s evolution. With an ample supply of sand along the shoreline of an island, island chain, or the mainland, the shore will widen (“prograde”) in a seaward or lateral (downdrift) direction, thus accreting and expanding the beach by littoral drift . Littoral drift is defined as the transmission of sand between the high and low tide levels by the transport of breaking waves and by wave-related littoral currents in the nearshore zone seaward of the low tide line. The low and high tide lines will shift seaward and a new foredune ridge parallel with the beach will form landward of the changed position of the high tide line. The low zone between the new and the previous foredune ridge is called a “swale.” Continuation of this seaward-building process will result in a "strandplain," which consists of relict dune ridges and intervening swales. In this fashion, extensive beach areas will eventually be added to and island or the mainland. This process constructed most of the northern Gulf islands after their initial emergence from the narrow, submarine shoals on the shallow nearshore seafloor.

The Chandeleur Islands of southeastern Louisiana (see fig. 2) evolved by a different type of island development—the transgressive (landward retreating) style of island evolution. In this case, landward shift or "rollover" of already formed barrier islands occurs after their initial formation. As the front beach of the islands is eroded and cut back, the shoreline of the islands will retreat landward. The eroded sand is washed landward across these islands by storms and deposited on the lagoon floor just behind the marshy lagoonal shoreline of the transgressive islands. The marsh builds up on this fill and the lagoonal shoreline will occupy a more landward position. During consecutive hurricanes, the islands will migrate over their own lagoonal deposits landward.

Most transgressive barriers will continue to evolve and not be submerged as long as landward retreat is possible (Leatherman, 1988); the Louisiana barriers are an exception to this rule. Here the land surface is rapidly subsiding along the periphery of the Mississippi River delta complex. Therefore, the barrier sands are sinking below the surf zone and are permanently lost to the shore.

Eolian Processes

Overwash and dune processes work together to move sediment landward at Gulf Islands National Seashore. Eolian transport results in the formation of dunes whenever sand can be moved from a beach or washover fan into an area that contains an "anchor"—either vegetation or fences. Any resistance to air flow leads to the deposition of sand around these anchors. Grasses play an important role in the process of forming dunes by serving as baffles to the flow and by growing upward and outward through the accumulating sand. In certain locations, such as the Province Lands of Cape Cod, Massachusetts, dunes can remain stabilized by vegetation for centuries if not disturbed by human activities (Leatherman, 1988). Once protective cover is destroyed, however, prevailing winds begin to move sand into previously stabilized areas of vegetation. In this way, a migrating dune can bury forests, ponds, and bogs.

After a storm event and under fair-weather conditions, dune systems redevelop from washover sediments and through sediment delivery to the beach face. Redevelopment depends on the redistribution of sediment to the nearshore during the storm (Sallenger, 2000) and the availability of sediment from alongshore (Psuty, 1992). Variability in the availability of sediment from nearshore and washover deposits in combination with vegetation cover can lead to alongshore variations in the extent and height of frontal dune morphology. Resulting dune development can reinforce alongshore patterns in overwash and breaching during subsequent storms (see "Restoring Dunes" section). In areas where frequent and extensive overwash occurs, dune fields tend to develop as a mosaic of alongshore patches that vary in age and composition (Stallins and Parker, 2003). While the dunes will obstruct overwash penetration, surge water may be forced into the intervening areas of low elevation, which can become overwash conduits (Wright et al., 1970). According to Houser and Fagherazzi (2006), the concentrated flows within these conduits could impact adjacent foredunes through lateral erosion, which could increase overwash penetration where dune height is variable.

Nearshore Sediment Transport

Tides, longshore and cross-shore currents, and the wind (see "Eolian Processes") all cause sand movement along a shoreline. In microtidal environments such as those of the Gulf Coast the tidal range is less than 2 m (6.6 feet). Though tides play a significant role in inlet migration and wetland formation (see "Wetlands and Ponds") in both microtidal and mesotidal (2–4 m [6.6–13 feet]) environments, barrier islands in microtidal environments are dominated by waves rather than tides. Because the volume of tidal exchange is insufficient to maintain inter-island passes in microtidal environments, islands in such areas often tend to be long and narrow, separated by relatively few inlets (passes). The growth rate of a flood tidal delta is a measure of the amount of sand being trapped behind the inlet. A portion of sediment moving along a coast is swept through an inlet and into a lagoon by flood currents. Because flood-tidal currents quickly dissipate in the lagoon or bay water where wave energy is low, sand settles out to form a tidal delta. If ebb-tidal currents are dominant, the sediment in the ebb current, combined with sand carried toward the pass in the littoral drift, will form larger ebb-tidal deltas off the seaward terminus of the inlet. Flood tidal deltas serve as the platforms upon which salt marshes (see “Wetlands and Ponds”) can develop.

The longshore or littoral current is formed by waves approaching the coast at an oblique angle and results in the movement of sand and other materials (drift) in the nearshore zone. Starting in the 1950s, investigators interpreted the sediment transport at Gulf Islands National Seashore as a unidirectional (westward), integrated model with a single source of sediment located east of Grayton Beach, Florida. However, in the 1990s, researchers (e.g., Stone et al., 1992) began to propose a more complex model, which incorporates a cellular, non-integrated, longshore drift system with three, independent sediment sources. The three sources of sediment are (1) the Pleistocene barrier island complex along Grayton-Mirimar Beach, (2) Pensacola Beach on Santa Rosa Island, and (3) onshore transport across the inner shelf between Pensacola, Florida, and Morgan Point, Alabama.

Stone et al. (1992) presents evidence that suggests that net sediment transport is composed of five mature cells; in one of these, the net drift is directed eastward. Furthermore, this study considers the net sediment transport as “non-integrated” because transfer between cells is insignificant. The eastern half of Santa Rosa Island (cell I) receives sediment from a Pleistocene coastal deposit east of Destin that acts as an eroding “headland.” Western Santa Rosa Island (cell II) may be supplied by an “internal” source at Pensacola Beach. The three remaining cells, extending from Pensacola Pass west to Morgan Point, receive material by direct onshore transport from the inner shelf.

- Cell I—Mirimar to the Navarre–Pensacola Beach region; net westward transport that uniformly decreases in magnitude downdrift
- Cell II—The remainder of the coast to Pensacola Pass; net westward transport
- Cell III—The eastern few kilometers of Perdido Key; net easterly drift indicating the importance of Pensacola Pass as a net sediment sink
- Cell IV—Eastern Perdido Key to Perdido Pass; net westward transport
- Cell V—Romar Beach to the western tip of Morgan Peninsula; net westward transport

While relatively robust models exist for the prediction of longshore sediment transport, this is not the case for the cross-shore component, which is generally responsible for beach profile change (Aagaard et al., 2002). The relative importance and directional attributes of the cross-shore component will determine the magnitude (and direction) of the net transport. According to Aagaard et al. (2002), the general scientific consensus in cases when waves are breaking is that sediment transport tends to be directed offshore. The ensuing profile response is a seaward migration of nearshore bars. During conditions with non-breaking waves, the transport is assumed to be directed onshore. Moreover, on gently sloping beaches, modeling predicts a tendency for onshore-directed sediment transport due to incident waves. On steeply sloping beaches or in the inner part of the surf zone, modeling predicts a tendency towards offshore sediment transports as a result of undertow.

Overwash

Overwash occurs when storm waters exceed the elevation of the adjacent land, and ocean water flows onshore. The overwash processes commonly transport large volumes of sand onshore where it is deposited as fan-shaped features (i.e., “washover fans”). Overwash areas, which are indicators of hazards to coastal development, are typically characterized by low elevations adjacent to the back beach, absence of dunes, and either barren or sparse vegetation. Storm flooding in broad overwash areas is normally by sheetwash.

Scouring and erosion are common in narrow overwash areas where the flow of waves and currents is restricted. During hurricanes and some winter storms, the overwash waves and currents can open new inlets on barrier islands, destroy bridges and roads, and transport sand inland more than a mile from the shore, blocking roads and filling parking lots (USGS Coastal and Marine Geology Program at http://coastal.er.usgs.gov/coastal-classification/class.html [accessed December 18, 2006]).

Sea-Level Rise

Throughout geologic time sea level has always been rising or falling relative to the land surface. The last major change in sea level occurred during the most recent Pleistocene ice age when global sea level was approximately 410 feet (125 m) below present (Fairbanks, 1989). Starting about 18,000 years ago and until 8,000–6,000 years ago, melting of ice sheets on a global scale rapidly increased the volume of water in the world ocean (Fairbanks, 1989; Otvos, 2004b, 2005a–d). In addition, geomorphic evidence from the slowly inundated Cat Island strandplain indicates that tectonic subsidence substantially added to the effect of global eustatic sea-level rise in the St. Bernard subdelta areas of the Mississippi River during the Holocene (Otvos and Giardino, 2004; Otvos and Carter, 2007).

The worldwide trend in sea-level rise applies directly to Santa Rosa Island and Perdido Key, which are located near the tide gauge at the Pensacola Municipal Pier (No. 8729840; 30º24.30 N, 87º12.70 W), and to the Mississippi barrier islands. Burdin (1990) indicates the similarity and compatibility between the Biloxi, Mobile, Pensacola, and Dauphin Island USACE tidal gage records. Burdin (1990) cites 0.18 cm/yr sea-level rise for Biloxi, 0.15 cm/yr for Mobile, and 0.23 cm/yr for Pensacola. The average seasonal cycle for Pensacola ranges from a low of -0.13 feet (-0.04 m) in January to a high of +0.7 feet (+0.20 m) in September as a result of thermal expansion of seawater in summer and variations in the wind stress field.

Melting of the polar ice caps continues to be a major cause of rising sea level, and the rate of rise is expected to accelerate in the future as a result of increasing global temperatures, driven by higher levels of carbon dioxide in the atmosphere (Leatherman, 1988). The scientific community has provided credible forecasts and serious warnings about global warming for nearly 30 years, and recent literature confirms (e.g., Houghton et al. [IPCC], 2001; The Presidents of National Science Academies, 2005) a scientific consensus that most of the warming in recent decades can be attributed to human activities.

Storm Events

The strong onshore winds that accompany tropical storms and hurricanes stack water against the ocean side of barrier islands, creating a storm surge. During the scoping meeting, Chris Blount (MS student, Georgia Institute of Technology–Savannah) presented information about the Hurricane Katrina–related storm surge at Gulf Islands National Seashore. This study also included a damage assessment. Investigators from Georgia Tech took measurements on the Mississippi islands from September 2005 through March 2006. Hurricane Katrina was larger in spatial extent than Hurricane Camille (1969)—the last "great hurricane" in public remembrance. On Cat Island, Hurricane Katrina's storm surge exceeded 20 feet (6 m), as indicated by debris in trees. The storm surge on West Ship Island at Fort Massachusetts hit the top of the fort wall at about 23 feet (7 m) above sea level. Most of the fort–covering earth mound above that level remained, despite the storm waves (Otvos and Carter, 2007). At the fort, mud lines were visible, water-borne debris was wrapped around the rails, and bricks at the top of the fort were eroded. Throughout the islands, bark was stripped from trees, and branches were broken during the storm. East Ship Island lost all of its pine trees during the storm (Ervin Otvos, University of Southern Mississippi, written communication, February 26, 2007). Investigators estimate that Horn Islands will lose 80% of its dense pine forest by early 2007 as a result of the combined effects of Hurricane Katrina and subsequent drought-driven salt toxicity (Gary Carter, Gulf Coast Geospatial Center, personal communication to Ervin Otvos, University of Southern Mississippi, 2007). A ship was stranded and, except for the fort, all NPS facilities were destroyed on West Ship and Horn islands.

Storm surges enable large waves to reach far into the interiors of barrier islands, at times breaching the islands. This overtopping process causes the transfer of sand from the seaward face to the backside of the barrier, producing a system of overlapping and coalescing washover fans that comprise the back-island flats (see “Hurricane-Generated Features” section). This is the principal mechanism by which barrier-island systems migrate landward in response to rising sea levels (Leatherman, 1988).

Another significant effect of storm events is the excavation of new tidal inlets. This type of barrier breaching is more likely to originate from the bay side than from the ocean side. According to Pinet (1992), the excavation results from a combination of factors. First, the bay becomes swollen with water due to abnormal storm precipitation, increased runoff from both the mainland and the barrier island, and a large tidal-inlet inflow driven by the storm surge offshore. Second, the strong onshore winds that lash the area create a storm surge not only against the seaward side of the barrier but also against the mainland, so that the water surface of the bay slopes downward toward the barrier island. As the storm and its onshore winds dissipate, water in the bay sloshes back against the barrier, occasionally overtopping the island at its most vulnerable, low-lying points and cutting a channel through it. The new inlet may then serve as a discharge conduit for the large volume of excess water trapped in the bay. Finally, the process of inlet construction may be enhanced by winds that veer from an onshore to an offshore direction as the storm center passes the site, blowing bay water though the newly formed inlet.

In many cases, the storm-generated inlet is short-lived because the nearshore drift of sand quickly closes the passage on its ocean side. However, along narrow barriers that have few tidal inlets, such as the Gulf Islands, some breached inlets may deepen and widen to become principal “exchange routes” for bay and ocean waters. For instance, the storm surge during Hurricane Camille (1969) created the pass between West Ship and East Ship islands.

According to the USGS Coastal and Marine Geology Program, the natural coastal attributes that are considered to have the greatest influence on storm impact and landward sediment transport are (1) the presence of overwash zones, (2) dune height (elevation) and continuity, (3) beach width, and (4) the presence or absence of emergent sandbars. The human alterations that typically influence storm impact and landward sediment transport are (1) density and type of development and (2) the presence of stabilization structures.

Geologic Resource Management Issues

Hurricanes and tropical storms are major factors shaping the coasts of northwestern Florida and Mississippi. In the past 10 years, northwestern Florida has been directly impacted by five hurricanes: Opal (1995), Erin (1995), Georges (1998), Ivan (2004), and Dennis (2005). Hurricanes Katrina and Rita (2005) indirectly impacted northwestern Florida. Forty-eight hurricanes came ashore on the Florida Panhandle between 1885 and 1985 (Wolfe et al., 1988). According to Muller and Stone (2001), the Gulfport, Mississippi area, experienced 21 tropical storms and 10 hurricanes (categories 1–5) from 1901 to 2000. Moreover, with warming of Atlantic sea-surface temperatures, the frequency and magnitude of these storms along the Gulf Coast has increased (Houser and Fagherazzi, 2006).

As significant as these storm events are, however, other issues related to the geologic features and processes at the national seashore are of equal management concern. These issues were not prioritized during the scoping meeting in September 2006, with the exception of determining sediment budget, which park managers identified as their highest priority. Hence, sediment budget is listed first, followed by the other issues in alphabetical order.

Sediment Budget

The beach and nearshore environments of the mainland coast of Mississippi and Florida have been subject to much human modification since the early 1850s, as shown on the first relatively accurate topographic maps of the coast (Meyer-Arendt, 1994). As a result, the Gulf Coast exhibits a dynamic interaction between human activities and the coastal environment. Past investigators have analyzed sediment changes in terms of gains and losses (e.g., Meyer-Arendt, 1994). Sediment gains include fill (e.g., pier and wharf construction, highway widening, and commercial and recreational expansion), dredge and fill, shell deposition, and artificial beach nourishment, all of which have extended the mainland shoreline seaward into the nearshore zone. Sediment losses occur as a result of sand displacement by waves and winds, including losses that occur during storm events. Dredging for channel maintenance and for dredge-and-fill construction, with redistribution at other subaqueous and subaerial sites, also accounts for sediment removal from the system (see "Dredging and Beach Nourishment").

During the September 2006 GRE scoping meeting, park mangers indicated that determining the sediment budget for Gulf Islands National Seashore was the highest priority with respect to making decisions about geologic resources, for example, knowing where dredged material should be placed. During the scoping meeting, Jim Flocks (USGS) mentioned that park managers may find it useful to investigate programs that consider the "beneficial use of dredged material" as a guide to making decisions. One such program is the Louisiana Department of Natural Resources, Louisiana Coastal Area Restoration project; the U.S. Geological Survey is a collaborator in developing a science plan for this project.

Determining a sediment budget would answer the questions: What is the source of the sand? Is it still coming? What are the sinks for the sand? The modeling portion of the mapping plan will help to answer these questions (see "Geologic Mapping for Gulf Islands National Seashore"). The following list highlights other questions identified during scoping:

- What are the long-term ramifications of not having enough sand vs. nourishing (i.e., "holding islands in space")?
- Should beach nourishment continue at Gulf Islands National Seashore; if so, where should sand be placed in order to maintain the system?
- Though individual islands seem to be losing sand, is the entire system losing sand?
- Though the system is highly manipulated, is it a naturally closed system?

Bluff Erosion

The bluffs in the Naval Live Oaks area are topographically the highest locations at Gulf Islands National Seashore. Otvos (2004a) identifies these bluffs as having been cut by wave erosion into tall, late Pleistocene and early Holocene sand dunes. Participants at the scoping meeting noted that local officials are considering a plan to stabilize the bluffs in Walton County, Florida, which may end a source of sand of the barrier island system. Though nearby, this source is thought to be minor (Ervin Otvos, University of Southern Mississippi, written communication, February 4, 2007). Moreover, bluff stabilization during recurring cyclonic storm activity and sea-level rise may be impossible to achieve (Ervin Otvos, University of Southern Mississippi, written communication, February 4, 2007).

Toscano (2004) identifies bluff erosion as a concern with respect to preserving archaeological sites at Gulf Islands National Seashore. Investigators have recognized 16 archaeological sites (middens) along the Santa Rosa Sound shoreline. These sites contain shells, pottery shards, artifacts, and in some cases concentrations of skeletal remains (Toscano, 2004); at least five levels of occupation or cultural periods are represented. Two of the 16 sites are "significant" and have been nominated as historic sites for the district. One of these—the Second Gulf Breeze Site—is being destroyed by bluff erosion. Because investigation of this site may answer many questions, but is vulnerable to erosion and looting, Toscano (2004) recommends preserving this site long enough to answer these questions, provided Native American authorities allow such investigation and preservation.

Development and Other Human Impacts

Many landowners have attempted to protect their property from storm waves or persistent beach erosion by placing structures along the shore. The structures commonly used to protect individual lots or entire communities from shoreline erosion are walls, riprap, and groins. Various types of walls differ in their purposes: seawalls are intended to hold back the sea, while retaining walls (bulkheads) are intended to hold back the land. In 1917, the U.S. Army Corps of Engineers constructed a seawall and groin on Ship Island in an attempt to protect Fort Massachusetts. During the mid-1960s, local citizens of a “Save the Fort” committee further constructed a circular rock jetty around the fort as a makeshift breakwater. Breakwaters—constructed of concrete or rocks placed parallel to the shore and seaward of the beach—are designed so that waves break, losing their energy on the structure and not on the beach.

Riprap consists of broken rock or sometimes other hard material (concrete) that is placed on the back beach parallel to the shore. Geotubes are composed of durable textile material formed into long cylinders that are filled with sand. The tubes, which are used instead of hard structures such as riprap, are normally placed in the back beach parallel to the shore. Walls, riprap, and geotubes are either naturally or artificially buried beneath sand of the back beach or dunes. Groins are usually short features composed of concrete, broken rocks, or wood arranged perpendicular to the beach. Groins can be individual structures but they are commonly spaced along the shore to form a field of groins. Jetties are constructed at tidal inlets and are intended to prevent sand from entering navigation channels. They are usually constructed of large blocks of rock and aligned perpendicular to the beach. Two small jetties are located on the Perdido Key side of Pensacola Pass. The effects of these particular structures are believed to be minimal because of their relatively small size and location, well back in the inlet throat (Dean et al., 2006).

In additional to hard structures along shores, the USGS coastal classification system identifies structures related to beach development, both residential and commercial. Parks constitute a special map classification because they typically consist of large areas that are natural in their morphology and vegetation but also commonly contain structural features such as parking lots, dune walkovers, bathhouses, and concession pavilions. In the case of Gulf Islands National Seashore, features of interest also include pipelines and other infrastructure related to oil and gas development (see “Oil and Gas Development”).

Storm impacts on developed coastal regions depend locally on the type and density of coastal construction. This is because artificial structures and topographic modifications tend to complicate wave and current interactions, and can accentuate the destructive forces of the storm. When high-velocity currents encounter rigid structures, the currents are typically deflected or focused, increasing turbulence and local scouring. Widely spaced and elevated buildings with small footprints cause minimal interactions with storm processes. By contrast, closely spaced concrete pilings or massive foundations of large buildings, swimming pools, and coastal defense structures locally increase erosion by focusing the flow between buildings and preventing the wave dissipating transfer of sand from the dunes to the beach and bars. Because hard structures do not store and release sand as dunes do, more sand erodes from the beach to satisfy the capacity of the strong waves and currents.

During the scoping meeting, resource managers highlighted another human impact related to development—asphalt debris from storm-damaged roads. A few inches of water can destroy a road, “eating away” the edges. In some areas, layers of asphalt have peeled off and drifted during submerged conditions, leaving large, irregularly spaced gaps in the paved surface. The material ranges in size from large piles of asphalt to grains mixed in with the sand. The National Park Service has been unsuccessful in obtaining funding for cleanup, and managers are concerned about the impact this material may be having on island habitats, in particular, turtle nesting grounds.

Falls (2001) mentions the "Old Quarry Trail" and "Old Borrow Pit Trail" in the Naval Live Oaks area, which highlights another impact—borrow pits on park property. The National Park Service considers such sites as "disturbed lands." The NPS Geologic Resources Division has a program that provides expertise for restoring disturbed lands to natural conditions.

Impacts to submerged park resources at the national seashore include artificial reefs, often tires, which recreational fishers dump in order to "enhance" accessible fish habitat by creating pseudo–hard bottoms. Additional recreational impacts include human-created access points in and between dunes, which may exacerbate erosion. Generally speaking, pedestrian traffic has an adverse affect on dune topography; human pathways carve foredunes into many separate sections. Moreover, vehicles passing across dunes can result in vegetation loss and blowouts, and these vehicular pathways may become overwash channels during storms. Vehicular traffic over existing washovers prevents reestablishment of dune vegetation on these bare regions. According to Leatherman (1988), vehicular traffic may accelerate the overwash process, resulting in greater barrier instability and more rapid landward retreat. Recent observations suggest that vehicular traffic traversing the beaches may benefit dune formation in areas where sediment is armored by shell lags, gravel, or asphalt because vehicles keep the sand churned up and available to be carried by the wind (Riley Hoggard, GUIS, e-mail communication reporting observations from Chris Houser, University of West Florida, August 15, 2006). However, past observations suggest that the physical forces applied to the sand by climbing and descending wheels result in a downward transport of sand (Leatherman, 1988). Hence, over the long term, the dune profile may be significantly lowered in those areas where numerous vehicles traverse the dunes.

Dredging and Beach Nourishment

Dredging occurs in three of the passes immediately adjacent to Gulf Islands National Seashore: Pensacola Pass (Florida), with sand disposal on Perdido Key and Santa Rosa Island; Ship Island Pass (Mississippi) with associated beach nourishment around Fort Massachusetts; and Horn Island Pass (Mississippi). Moreover, dredge spoil disposal from the deep Mobile Pass ship channel, which crosses the extensive ebb-tidal delta, may be diminishing or even terminating westward littoral drift, contributing to long-term island erosion downdrift along the Mississippi–Alabama island chain. This effect also impacts several of the other barrier islands that are flanked by regularly dredged navigation channels (Ervin Otvos, University of Southern Mississippi, written communication, February 4, 2007). Sand is not readily returned to the littoral sand transport system from remote deep Gulf sites and may be permanently lost (Douglass, 1994; Otvos and Carter, 2007).

Pensacola Pass

At present the dredging project of greatest concern for park managers is the proposed maintenance of the Naval Air Station (NAS) Pensacola shipping channel in Pensacola Pass. The U.S. Navy wants to excavate a channel 500 feet (152 m) wide and 46 feet (14 m) deep, which includes 2 feet (0.6 m) of advanced maintenance and 2 feet (0.6 m) of over-depth. Moreover, the U.S. Navy wants to dispose of material extracted from the channel on Santa Rosa Island and in the nearshore area and on Perdido Key. The pass is located between Perdido Key (on the west) and Santa Rosa Island (on the east) (see fig. 1). Acceptance of the material by the National Park Service is contingent upon compatible grain size, composition, and color with existing beach and nearshore sediments and the final plan-form design. As of September 6, 2006, the parties involved (i.e., Florida Department of Environment Protection, National Park Service, U.S. Army Corps of Engineers [USACE], U.S. Fish and Wildlife Service, and U.S. Navy), had reached an agreement on a revised placement plan (Larry Parson, USACE, [draft] memorandum of record, September 18, 2006). With respect to Gulf Islands the plan includes the following items:

- Santa Rosa Island, Fort Pickens unit (disposal area 2)—Limited to a maximum fill volume density of 85 cubic yards (65 m^3) per foot, the USACE will deposit 650,000 cubic yards (496,960 m^3) of material over a 4.3-mile (6.9 km) segment along the Fort Pickens unit. This material, composed of beach compatible sand, is proposed to come from various segments (B and D) of the channel.

- Perdido Key (disposal area 3)—Limited to a maximum fill volume density of 85 cubic yards (65 m^3) per foot, the USACE will deposit 2.88 million cubic yards (2.20 million m^3) of material from channel segments B and D over a 6.3-mile (10 km) segment of beach. Placement is proposed to occur over a two-to-three year period with single-event disposal of approximately 1.44 million cubic yards (1.10 m^3). To promote more rapid recruitment and recovery rates, material will be placed in alternating segments for each dredging event, leaving alternate segments unfilled. The intent is that after two dredging events approximately one year apart, this entire length of shoreline would receive up to 2.8 million cubic yards (2.1 million m^3) of material. The maximum berm height is proposed at 8 feet (2.4 m) with varying height and volume density in the alongshore direction to preserve natural overwash capabilities. Placement of the material will be segmented into four sub-disposal areas approximately 8,400 feet (2,560 m) in length with 4,700 feet (1,433 m) at a berm elevation of 8 feet (2.4 m), and 3,700 feet (1,128 m) at 5-feet (1.5 m) elevation.
- Nearshore area of Perdido Key (disposal area 4)—The USACE will deposit 870,000 cubic yards (665,163 m^3) of material from segment C of the channel just seaward of the primary bar system, landward of the -12-foot contour. The placement zone and recommended configuration would require approximately 40–50 cubic yards (31–38 m^3) per foot.

According to Browder and Dean (1999), recent shoreline changes in the vicinity of Pensacola Pass are dominated by the large dredging/nourishment project conducted between 1989 and 1991. The project created two major perturbations in the system: a substantially over-dredged channel and a large quantity of unstable sand alongshore. Moreover, dredging of Pensacola Pass has reduced the volume of the ebb shoals surrounding the inlet and created an overall loss of sediment from the littoral system. Also, wave refraction analysis suggests the possibility of a local reversal in net transport direction from westerly to easterly drift along Perdido Key, drawing sand off the downdrift shoreline back into Pensacola Pass (see also “Nearshore Sediment Transport” section).

The first nourishment project on Perdido Key (1985) placed almost 2.5 million cubic yards (1.9 million m^3) of sand along a distance of approximately 4,000 feet (1,219 m) (Browder and Dean, 1999). From fall 1989 to fall 1990, about 5.4 million cubic yards (4.1 million m^3) of sediment were placed over a distance of about 4.5 miles (7.2 km) (Browder and Dean, 1999). In 1990–1991, about 3.9 million cubic yards (2.98 million m^3) of sand was placed offshore at depths ranging from 19 to 20 feet (5.8–6.1 m) (Browder and Dean, 1999). Also according to Browder and Dean (1999), sediment placed at these depths is essentially lost to the island system. Whereas the sediments may move laterally as they settle, they may not be transported back to the beach or even the outer bar even by storm waves.

The National Park Services accepts the disposal of beach-quality material on and near Perdido Key to mitigate the “human-caused disruption” of the dredging in Pensacola Pass (NPS *Management Policies 2001*, Section 4.8.1.1). The National Park Service is attempting to conserve the natural processes and conditions that sustain resources in Gulf Islands National Seashore. Such processes include overwash and shoreline migration, which preserve island width and elevation, and allow the island to migrate toward the mainland in order to avoid becoming submerged by rising sea levels. Disposal of sand material in the Fort Pickens unit is also intended to mitigate the influence of the dredging of Pensacola Pass (Browder and Dean, 1999). This beach restoration, along with possible foredune restoration, may also serve as shore protection associated with planned road reconstruction in early to mid-2008 (Linda York, NPS Southeast Regional Office, written communication, February 6, 2007).

Construction of the Pensacola channel was authorized in 1878; the first modification of the pass occurred in 1883 when a 25-feet- (7.3 m) deep entrance channel was excavated. In 1959 the channel was widened and deepened to 37 feet (11.3 m) deep with disposal of the dredged material on Santa Rosa Island (Florida

Department of Environmental Protection, 2000). The latest dredging project in 1991 deepened and widened the channel to 48 feet (14.6 m) and 800 feet (244 m) respectively to accommodate a naval aircraft carrier (Browder and Dean, 1999). The dredged material was placed on Perdido Key (Florida Department of Environmental Protection, 2000). In total, approximately 45.8 million cubic yards (35 million m^3) of material have been removed from the channel, and only 18.6 million cubic yards (14.2 million m^3) of that volume were disposed on or near the adjacent shoreline (Browder and Dean, 1999).

Maintenance dredging of the Pensacola Pass entrance channel has not occurred since 1991 because the aircraft carrier was not harbored at NAS Pensacola after all (Florida Department of Environmental Protection, 2000). However, several "emergency" dredge projects have occurred over the years to facilitate a naval need, which is usually economic as the City of Pensacola wants to entice a passing task force or large naval vessel to make a port call (Riley Hoggard, GUIS, written communication, February 7, 2007). The sedimentation rate of the channel is approximately 300,000 cubic yards (229,000 m^3) per year and the depth of the channel was approximately 40 feet (12.2 m) in 1997 (Florida Department of Environmental Protection, 2000).

Ship Island Pass

Gulfport shipping channel in Ship Island Pass, a federally maintained channel to Gulfport, Mississippi, was established by the River and Harbor Act of 1899. The act provided for a 26-feet- (7.9 m) deep channel between Ship (now West Ship) and Cat islands, which was deepened to 32 feet (9.8 m) from 1948 to 1950 to accommodate naval ships (Boom et al., 1991). The channel's central location allows access to world markets via its port at Gulfport, Mississippi, which has been referred to as "the most accessible port on the Gulf of Mexico." In 1989 the U.S. Army Corps of Engineers discovered that the western tip of Ship Island had migrated westward approximately 38 feet (11.6 m) per year since 1848 (Boom et al., 1991). Dredging of Ship Island Pass may have halted this migration process (Boom et al., 1991).

In the late 1850s, Fort Massachusetts and associated sites were built at what was the center of the western end of Ship Island. Hurricanes and winter storms nearly destroyed the fort several times during construction (Kanze, 2001). Beach nourishment has occurred at this site periodically since 1974, with the most recent nourishment project completed in 2002. According to Henry (1977), the March 1974 nourishment (using 500,000 cubic yards [382,277 m^3] of sand dredged from Ship Island Pass) deteriorated rapidly (>3.3 feet [1 m] per month) during the late fall–early spring of 1974–1975 as a result of winter storms. Erosion of the fill continued until the circular rock jetty was reexposed in 1975; by August 1977 the beach had retreated to within 50 feet (15 m) of the fort. Subsequent nourishment has been monitored and shown to have rapidly eroded (from about 13 feet [4 m] per year to about 82 feet [25 m] per year) as a result of sound-side processes and northwestern and northeastern storms during the winter months (Chaney, 1993; Stone et al. 1998a,b). Each period of erosion eventually left the fort surrounded by water despite the circular revetment, which has done little to retain sand near the fort (Toscano, 2004).

Dredging of the pass has been done periodically since before 1918 (Shabica et al., 1993), and westward migration and extension of the island was replaced by a net loss of 4.5 acres (1.8 ha) per year as the island migrated into the dredged channel. The pass was relocated 1,900 feet (579 m) to the west in 1993, in order to allow West Ship Island to migrate unimpeded for 50 years (according to USACE reports cited in Shabica et al., 1993) but the old channel was never backfilled (Chaney, 1999) and is now used as an impoundment to prevent the new channel from filling (Riley Hoggard, GUIS, personal communication to Marguerite Toscano, GIP, 2004). Oivanki (1995) studied areas of the Mississippi Sound in search of other sand resources in lieu of channel-derived dredge spoil, citing the relocation of the channel as a situation that made this source no longer economically feasible. Dredge spoils from the new channel are normally deposited in the Gulf of Mexico, in the littoral zone of Cat Island, and thinly layered in the Mississippi Sound. Although Henry (1977) considers periodic beach nourishment alone an inefficient means of protection for Fort Massachusetts, plans for inlet maintenance also include the periodic placement of dredge spoil on the beach surrounding the fort as arranged by the National Park Service. In 1996 and 2002, however, the old channel (not the new) was still the source of sand for the beach nourishment, thus maintaining the sand sink that is preventing westward island migration (Toscano, 2004).

Horn Island Pass

Dredging activities also occur in Horn Island Pass at the west end of Petit Bois Island for the Pascagoula Port shipping channel. Participants on the field trip noted the spoils pile—"Sand Island"—west of the channel, toward Petit Bois Island. Shabica et al. (1993) estimates Petit Bois Island will cease to exist in about 75 years as a result of this dredging.

Two deepwater harbors at the Port of Pascagoula with 38 feet (11.6 m) and 40 feet (12.1 m) channel depths provide direct access (8 miles [13 km]) to major shipping lanes in the Gulf of Mexico. Tonnage at both public and private docks ranks the Port of Pascagoula as the 16th largest port in the nation and Mississippi's largest port. Pascagoula is the "industrial center" of Mississippi; a Chevron refinery, the largest in the United States, is located there.

Groundwater

During the scoping meeting, park managers voiced their desire to know more about the groundwater resources at Gulf Islands National Seashore, in particular, to identify areas where groundwater is being discharged. Ron Hoenstine (Florida Geological Survey) thought that resistivity and temperature-change studies could identify sources of groundwater discharge, and resistivity data could be gathered at the same time as the seismic and side-scan sonar survey for geologic mapping. Management interest is in response to development (e.g., use, contamination, and saltwater intrusion) in the vicinity of the national seashore, and how this will affect park resources, as well as identifying how groundwater affects salinity levels, which determines oyster and scallop habitat. According to Anderson et al. (2005), "Studies have shown that regional groundwater flow is strongly affected by pumping." For instance, near Pensacola water levels in the sand-and-gravel aquifer dropped as much as 26 feet (8 m) between 1940 and 1973 in areas with heavily pumped well fields (Trapp, 1975). Nearby streams also showed decreased base flow, indicating that some of the water was intercepted by nearby wells (Katz and Choquette, 1991).

A sand-and-gravel aquifer underlies most of northwestern Florida, extending from central Walton County northwest into Alabama and south to the Gulf of Mexico (Cooper et al., 2005). This aquifer is composed of late Miocene–early Pliocene sand intervals of variable thickness, which are encased in a several hundred feet thick, predominantly muddy sequence. The aquifer is the primary source of drinking water in Escambia and Santa Rosa counties and a secondary source in Okaloosa and Walton counties (Katz and Choquette, 1991). However, rising water demands in Florida have increased the importance of the sand-and-gravel aquifer as a water source in Walton and Okaloosa counties (Guvansen, 2000). The thin Pliocene Citronelle formation and late Pleistocene deposits, primarily the Prairie Formation, represent much thinner and less significant sand-and-gravel aquifers (see table 2).

The geologic units that contain freshwater at the Davis Bayou unit of the national seashore are of late Miocene to early Pliocene age (Christmas, 1973; Otvos, 1985b, 1997). The freshwater is located in layers of sand that occur irregularly at depths ranging from 1,200 to 3,000 feet (366 to 914 m) below the surface (National Park Service, 1978). Below these depths, warmer saline water is present, as groundwater salinity generally increases with depth (Christmas, 1973; Otvos, 1985b, 1997). Freshwater is located in the geologic strata of approximately the same age under the barrier islands of Mississippi (National Park Service, 1978). Artesian water is provided from the sand beds and lenses of the Miocene formation at depths of about 590 to 800 feet (180 to 244 m) below sea level.

Mississippi Coastal Improvement Project

Though the Mississippi Coastal Improvement Project will most certainly result in many anthropogenic impacts (see "Development and Other Human Impacts"), its scale warrants a separate discussion. The project is probably the most severe threat to the Mississippi barrier islands and Gulf Islands National Seashore ever (Riley Hoggad, GUIS, written communication, February 7, 2007). During the September 2006 scoping meeting, John Baehr (U.S. Army Corps of Engineers) provided information and answered questions about this project. At the request of the governor, the U.S. Army Corps of Engineers is developing a long-term comprehensive plan for protecting the Mississippi coast, which includes five lines of defense. Rebuilding the offshore barrier islands in Mississippi to pre-Hurricane Camille (1969) conditions is the first line of defense and would include elevating the islands to 20 feet (6 m) above sea level and closing the pass between East Ship and West Ship islands that opened during Hurricane Camille. The Corps determined the pre-Camille footprint of the Mississippi islands from USGS reports. Preliminary modeling indicates that reconstructing these conditions would provide some protection from storm surges and waves in the Pascagoula area only.

The placement of sand on the islands would require 50 million cubic yards (38.2 million m^3) of compatible beach quality sand. For comparison, typical beach nourishment projects use 2–3 million cubic yards (1.5–2.3 million m^3) of sediment, so the magnitude of this project is enormous. The National Park Service reviewed a draft environmental assessment from the U.S. Army Corps of Engineers for studies to locate suitable quantities of sand in submerged lands in and near the offshore barrier islands. The review document indicates that the Corps of Engineers needs more work on the environmental assessment (Jerry Eubanks, GUIS, letter [L7619 {GUIS-RM}] to Larry E. Parson, USACE–Mobile District, July 25, 2006). As of September 28, 2006, the geotechnical assessment of potential sediment sources for barrier island restoration was "shelved" for budget reasons; however, the concept has not been dropped (Lindsay McClelland, NPS, notes from USACE principals' briefing, September 28, 2006).

Three million cubic yards (2,293,665 m^3) of sand is needed to construct the second line of defense, coastal dunes, which provide 20-year storm protection. The Prairie Formation (see table 2), which underlies the land surface, may provide an on-land sand source and would be served by a commercial operation. To protect the roads, sheet piling (4 to 6 feet [1.2 to 1.8 m] high) is proposed. The other lines of defense include 15-feet- (4.6 m) high coastal dunes on the mainland shore where beaches were created in the 1950s. Coastal roads would be elevated, reinforced with sheet piling, which resemble structures in Galveston. A category 5 barrier is being developed to protect against a "perfect storm" with a 38.5-feet (11.7 m) storm surge. This structure would be 40 feet (12 m) high, crossing two bays with Thames River–like structures. Engineers are investigating ways to alleviate ponding of water behind the structures, including gravity drains with storage and pumps. To accommodate a 3,000+ year storm surge, the Corps of Engineers proposes to construct gated structures in the Bay of Biloxi that would cost $1 billion. Structures in the Bay of Saint Louis would cost $2 billion. Pascagoula would need to be protected with a ring type structure, which will likely be unacceptable to that community.

This plan considers sea-level rise impacts, including elevating roadways 3–4 feet (0.9–1.2 m). To test the ramifications of the first line of defense, a sediment transport model is underway. Sediment needed for this work is a volume equivalent to 10 feet (3 m) deep by 5 square miles (13 km^2). A possible source for this sand is 30 million cubic yards (22.9 million m^3) of river sands stored 60 miles (97 km) north of Mobile, Alabama.

Oil and Gas Development

Oil and gas exploration and development in the Gulf Coast region started in offshore Louisiana in the 1940s. No oil and gas wells have been drilled within the boundaries of Gulf Islands National Seashore, and no federal mineral leasing is allowed within the unit. However, near the national seashore widespread oil and gas development is currently occurring to the north in onshore salt basins, and offshore to the south and west in the Gulf of Mexico. In the eastern Gulf of Mexico in the vicinity of Panama City, Florida, to Mobile, Alabama, 81 exploratory wells have been drilled in federal waters. Natural gas, condensate, and crude oil were discovered in 13 of these exploratory wells (Mineral Management Service, 2006).

In 1972, the State of Mississippi conveyed to the United States via quitclaim deed "all right, title and interest in and to" approximately 64,000 acres (25,900 ha) for inclusion in Gulf Islands National Seashore. The deed transferred the mineral estate beneath the conveyed lands to the U.S. government but reserved the state's right to extract oil and gas from the conveyed lands by operations conducted outside the boundaries of Gulf Islands National Seashore, without compensation to the U.S. government. Section 6034 of the Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Tsunami Relief, signed into law on May 11, 2005, expands the rights of the state (including lessees, contractors, and permittees) to explore for and develop oil and gas resources beneath Gulf Islands National Seashore. The act allows the State of Mississippi to directionally drill from locations outside the national seashore to subsurface bottom-hole locations within the seashore. This provision of the act could result in increased well drilling and siting of facilities immediately adjacent to the boundary of the seashore. In addition to allowing drilling and production activities, the act also allows seismic operations inside the boundaries of the seashore, but only on the surface estate conveyed by the State of Mississippi to the U.S. government. Offshore drilling on federal oil and gas leases could also occur in federal waters outside but within view of the national seashore.

The National Park Service would regulate both the seismic activities and the directional drilling operations associated with state leases within the national seashore through NPS Nonfederal Oil and Gas Rights Regulations (36 C.F.R. Part 9 Subpart B). These regulations are limited to controlling activities within park boundaries. They do not control surface facilities, including directional drilling facilities located outside the seashore. Outside Gulf Islands National Seashore, the National Park Service would encourage oil and gas operators to adopt mitigation measures that protect park resources and values.

When conducted properly, impacts from seismic surveys are limited to the duration of the survey and include noise generated from explosives, equipment emissions, increased boat traffic, visual intrusions, and possible restrictions on visitor access. Scientific evidence suggests that the detonation of seismic charges may impact marine mammals (Cart, 2005). Once seismic surveys are completed, typically little or no lasting impacts are evident, with the exception of disturbance to sea-grass beds and possible impacts on individual marine mammals.

Potential impacts on the resources and values in Gulf Islands National Seashore from oil and gas drilling and production include impacts on park resources from spills of hydrocarbons and other toxic and contaminating substances from the drilling/production rigs, vessels, and pipelines; trash from the drilling and production operations; ground subsidence occurring from production of hydrocarbons; views of the offshore drilling and production rigs; and encroachment on wilderness values (e.g., Horn and Petit Bois islands are designated wilderness within Gulf Islands National Seashore).

Preserving Historical and Cultural Resources

According to Toscano (2004), more than 40 archaeological and historic sites are located in Gulf Islands National Seashore. These sites include Holocene middens and occupation sites, early Spanish settlements, Civil War forts, and early 1900s-to-WWII batteries and artillery, which are situated in a wide range of coastal environments, including elevated mainland areas, eroding bluffs, and exposed low-lying barrier islands. Scoping participants also identified shipwrecks as a submerged cultural resource in need of preservation. Factors affecting the physical settings of the cultural sites include hurricanes and cold fronts, storm surges, sediment erosion and transport, inlet dredging, and sea-level rise.

The National Park Service considers geologic and meteorological processes as natural resources; hence, these processes would normally be allowed to alter the shoreline without intervention. However, cultural resources at Gulf Islands National Seashore are also subject to protection and preservation under NPS management polices. Since its authorization in 1971, researchers have studied the resources of Gulf Islands National Seashore, resulting in sufficient insight and understanding of local processes and anthropogenic impacts. These studies also provided a number of practical recommendations for preserving the cultural resources at risk such as large forts, which cannot be moved, along with their coastal and historical settings.

Toscano (2004) presents options for preserving cultural resources in this rapidly evolving coastal setting. Depending on the site, alternatives include allowing natural processes to prevail where natural remediation of erosion could reasonably occur, assisting natural methods that might speed ongoing constructive natural processes, and in worst cases where natural processes are predominantly destructive, intervening with mechanical or structural technologies. All options are presented within the framework of future sea-level rise scenarios and consistency with NPS policies.

Preserving Sea-Grass Habitat

In 1949 sea-grass beds in the Pensacola Bay system were extensive, but by 1975 the Florida Department of Environmental Protection had documented these beds to have receded or disappeared. In Perdido Bay, sea grass within the whole system declined nearly 50% from 1940 to 1987, with some specific areas experiencing sea-grass coverage losses of greater than 80% (Handley et al., 2003). Big Lagoon in the Perdido Key area and the area north of Santa Rosa Island are the only water bodies within the Pensacola Bay watershed that still contain moderately diverse sea-grass beds. Because of the decline of these sea-grass beds in recent years, the Florida Department of Environmental Protection, Ecosystem Restoration Section, has been conducting sea-grass restoration in Pensacola Bay. Part of this program includes sea-grass monitoring to establish baseline data for sea-grass beds in Big Lagoon and the area north of Santa Rosa Island (Florida Department of Environmental Protection, 2001).

As in Florida, sea-grass distribution in Mississippi has declined noticeably over the past several decades. The total sea-grass acreage in the Mississippi portion of the national seashore was found to have decreased from 1,029 acres (416 ha) in 1956 to a mere 345 acres (140 ha) in 1987, though some increase was noted between 1993 and 1995. The largest concentration of sea grasses was found on the north side of Horn Island, where 417 acres (169 ha) in 1956 declined to 138 acres (56 ha) by 1987, and to only 14 acres (5.7 ha) by 1992 (Handley et al., 2003).

Scientific studies attributed sea-grass decline in these areas to increased turbidity and reduced water quality from dredging and filling in harbors and the intracoastal waterway; boat traffic; shoreline modification; residential, commercial, and industrial development; and hurricane-related effects (Kenney, 2006).

Rebuilding Roads and Other Infrastructure

Storm surges associated with Hurricanes Opal (1995) and Ivan (2004) caused considerable damage to infrastructure, coastal dunes, and associated habitats in Gulf Islands National Seashore. For example, both park roads on Santa Rosa Island—Fort Pickens Road and J. Earle Bowden Way (fig. 3)—were extensively damaged during these storms and during the 2005 hurricane season (i.e., Hurricanes Cindy, Dennis, and Katrina, and Tropical Storm Arlene). At the time of scoping in September 2006, both roads still remained closed to the public. The Fort Pickens campground, utilities, docks, and piers also remain in need of repair (Beavers and Selleck, 2005).

The 7-mile- (11 km) long Fort Pickens Road formerly provided visitors with vehicular access to the western end of Santa Rosa Island, including the historic Fort Pickens, a visitor center, and a campground. The 8-mile- (13 km) long J. Earle Bowden Way provided park visitors access to beaches and day-use facilities at Opal Beach. It also served as a commuter route between the towns of Pensacola Beach and Navarre Beach and as a secondary emergency-evacuation route from Santa Rosa Island.

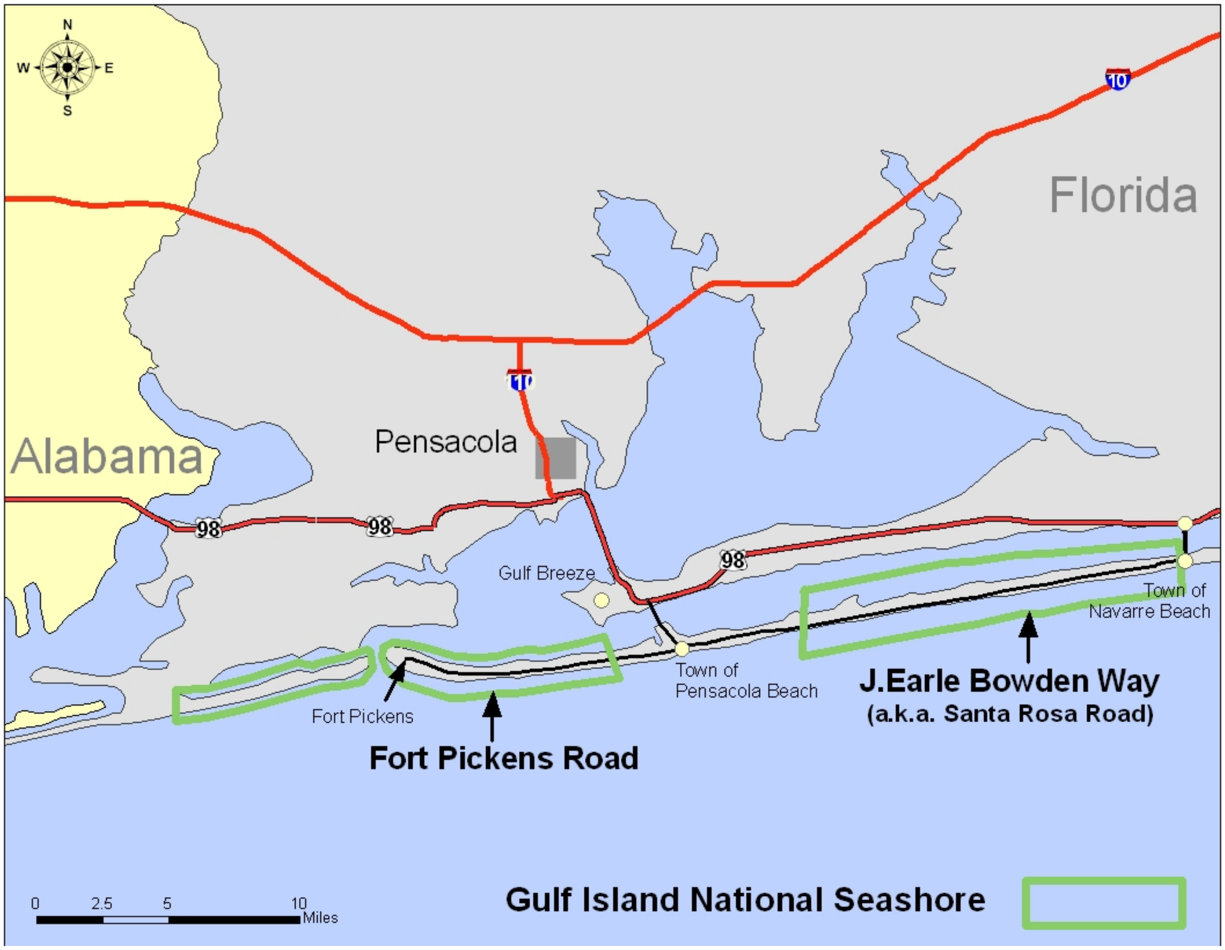

Figure 3. Location Map of the Fort Pickens Road and J. Earle Bowden Way on Santa Rosa Island (Florida). *Note*: Boundaries, indicated by green lines, are approximate.

Investigators from the University of West Florida have categorized the damage to the road using a combination of aerial photographs and ground-based assessments (Chris Houser, University of West Florida, written communication, February 9, 2007). They analyzed how proximity of the road and shoreline, elevation and width of the island, and offshore bathymetry affected the levels of damage. Sections of road with little to no damage were located close to the shoreline and associated with an above average island elevation (i.e., large foredunes or high and wide upper foreshore berms). These areas tended to be located in wider sections of the island (the cuspate forelands) with a dissipative (gently sloped) offshore profile. Sections of the road that sustained major damage or were completely destroyed (breached) tended to be aligned along the back of the barrier and in narrow sections of the island where the offshore profile was steep (reflective). These areas were also characterized by a low-island elevation (poorly developed foredunes or small berm) and no secondary dunes. Because island elevation, width, and offshore bathymetry are coherent alongshore, investigators conclude that damage to the road is geologically forced, and areas where the road received extensive damage will continue to be areas of concern.

The focus of post-hurricane rebuilding efforts at Gulf Islands National Seashore is on restoring visitor access to the Fort Pickens and Opal Beach areas of Santa Rosa Island. Specifically, the park's objective is to replace the roads to their former conditions. During the scoping meeting, Rick Clark (Gulf Islands National Seashore) expressed his belief that these two park roads will be rebuilt in some way, shape, or form; however, the general management plan (GMP) and geologic resource evaluation (GRE) (particularly the digital geologic map product) will advise decisions about rebuilding after future storm events. In particular, managers wish to identify “hot spot” areas subject to high rates of erosion and breaches in order to inform redevelopment of infrastructure.

The NPS Geologic Resources Division and Southeast Regional Office have been providing expertise and assisting Gulf Islands National Seashore staff during the process of evaluating alternatives for access restoration. Other participants in this process are the NPS Development Advisory Board, Federal Highways Administration (FHWA), the NPS Denver Service Center, and Florida Department of Transportation. Evaluating the alternatives (i.e., both non-road and road, with and without hard structures) involves considerations of costs; types, availability, and suitability of materials; and protection of features and processes of natural barrier islands (e.g., migration, sediment transport, and sand characteristics).

The evaluation process began in January 2006, when park managers hosted a value analysis/choosing by advantages (VA/CBA) workshop. Participants included representatives from the NPS Geologic Division, the NPS Southeast Region, the NPS Denver Service Center, Gulf Island National Seashore, the Federal Highways Administration, Florida Department of Transportation, and several road contractors. The VA/CBA process ranks alternatives based on available cost information and perceived advantages (benefits) as determined by workshop participants. In this case, participants were initially directed to identify the best alternative for reconstructing the roads, but participants also evaluated non-road alternatives.

After evaluating the costs and advantages of the various alternatives, the participants concluded that the best benefits/cost ratio would be achieved if the roads were not rebuilt. However, because the participants had been directed to identify road reconstruction alternatives, they then recommended that the Fort Pickens Road be reconstructed with sand dune protection. A ferry was also found to be a cost-effective option. The workshop participants then determined that the most cost-effective way to rebuild J. Earle Bowden Way would be to rebuild and realign this road in-kind, but FHWA representatives stated that the administration would not fund such an alternative. Therefore, the VA/CBA workshop participants recommended reconstructing J. Earle Bowden Way with a mix of hard structures (i.e., dunes, sheet piling, and armored shoulders).

Subsequently, the Federal Highways Administration informed the National Park Service that it would only fund the reconstruction of the roads if hardened structures were added to both. Although the Federal Highways Administration has offered no legal or regulatory justification for this requirement, the National Park Service has acquiesced to the FHWA position. Therefore, in two environmental assessments released in October 2006, the National Park Service proposed to reconstruct both park roads with a mix of protective hardened structures, including geoweb mattresses, articulated concrete block, sheet piling, asphalt aprons, and 20-feet- (6 m) deep parallel buried sheet piling.

During the public comment process, these environmental assessments and the proposals for hardened structures received many negative comments from individuals, scientists, organizations, and other government agencies. Therefore, the National Park Service continues to consider its options for restoring visitor access to Santa Rosa Island. In order to move forward on this issue, the National Park Service must work closely with the Federal Highways Administration to ensure a solid understanding of barrier island dynamics and to develop a road design that is appropriate for barrier island environments. The National Park Service may also need to develop more alternatives for restoring access to this part of Gulf Islands National Seashore, and publish additional environmental assessments or environmental impact statements in order to comply with the National Environmental Policy Act, NPS policies, and other NPS mandates.

Restoring Dunes

As noted during the field trip (part of the scoping meeting in September 2006), an anthropogenic swale and lag deposits (i.e., limestone from Mexico used as road base) are present in the Fort Pickens area of Santa Rosa Island, and road construction and maintenance in the Santa Rosa and Perdido Key units have impacted dune processes. These human modifications are coupled with impacts from recent hurricanes. Chris Houser (University of West Florida) is the principal investigator for a suite of studies that are examining dune recovery on Santa Rosa Island following Hurricane Ivan (2005). During Hurricane Ivan, foredunes in Gulf Islands National Seashore were destroyed or significantly reduced in height through direct wave erosion and the transfer of sediment to the back barrier by overwash. The post-storm morphology of Santa Rosa Island consists of a narrow beach face, multiple breach corridors, a washover terrace, and a remnant secondary dune that has been further eroded by Tropical Storm Arlene and Hurricanes Cindy, Dennis, and Katrina.

During the scoping meeting, Houser noted that the redevelopment of the dunes will direct Santa Rosa Island's response to future storms because dune morphology creates a recurring pattern for breaching; that is, areas with low dunes will experience overwash and breaching (a self-imposed pattern) during storm events. Large dunes near the shore inhibit overwash, causing sediment to be deposited near shore. Where the primary and secondary dunes are closely spaced, overwash was restricted and sediment erosion increased offshore—a situation analogous to having a large wide foredune.

In his correspondence with Riley Hoggard (Gulf Islands National Seashore), Houser reported two significant management implications resulting from this study on Santa Rosa Island. First, a swale seaward of the dunes in the Fort Pickens area is impeding sediment transport from the beach face and backshore to the dunes; the swale runs along a section of roadway about 2 miles (3.2 km) long. Though swales will naturally develop behind berms during post-storm recovery, this "swale" was also a by-product of the road itself. The swale was not dug by humans but is definitely human caused. As hurricane surge waters rushed across the roadway, the sand on the north shoulder was destabilized and washed away, thereby creating the swale. If a surge persists, the water eventually undermines the road and the road caves in. This is the mechanism for road destruction from hurricanes. The swale in question is a result of overwash following Hurricane Ivan (2004). The swale permanently retained water (and was referred to by some park staff as the "Fort Pickens River"). Hurricane Dennis (2005) moved considerable amounts of sand across the island, partially filling the swale. Although the swale no longer holds water, it is slightly lower than the surrounding area and stays moist. Houser has determined that the swale is capturing the blowing sand, inhibiting it from reaching and subsequently building the secondary dunes (Chris Houser, University of West Florida, correspondence with Riley Hoggard, GUIS, December 2006).

During the strong frontal winds on April 29, 2006, Houser and his students observed a dune in the Fort Pickens area to migrate more than 3 feet (1 m) to the north, which is substantial for a vegetated coastal dune. According to Houser, until the sediment supply to the dune is restored (through beach face and backshore recovery, or direct placement), the dune will not recover during periods of southerly (onshore) winds but may actually become an unanchored dune, if further rhizome exposure and vegetation damage occurs. Currently, the only way the sediment supply is building is through the small overwash events that occur during strong frontal winds; these events deposit sediment in washover fans behind the berm and in the swale. However, the time for the backshore to recover is not known, and some evidence indicates that the winds are quite complex in this area due to the steep-beach and deep-swale topography.

The second implication for management is that the erosion that occurs during onshore winds (from the south) is currently balanced by the small amount of sediment transport from the north during offshore winds. This sediment is coming from the washover terrace, despite the presence of a lag of shells and gravel. A study beginning in fall 2006 will examine the role of lag deposits on sediment transport over the washover terrace. Houser surmises that the shells which are in larger concentration in the Fort Pickens area may be nourishment material from Pensacola Beach. Additionally, a relatively high concentration of gravel and pavement from the road and road bed is a direct human alteration to the local environment. Without this lag, more sediment would be available to the dunes during periods of offshore winds, which are quite common during the winter.

While Houser has removed instruments from the site (for use in other studies), he and his graduate students are continuing to monitor the development of the dunes using erosion pins that they placed there at the start of the study in February 2006. They are planning to maintain these erosion pins for the next couple of years in order to determine the start of recovery and link that to the source of sediment, whether artificially placed or by natural processes (overwash). Moreover, in fall 2006, a graduate student will start to look at the cross-island environmental gradients (e.g., in moisture, transport, vegetation, and wind) that affect the rates of dune recovery at sites with different hurricane impact levels (e.g., inundation at Fort Pickens, and beach erosion at Eglin Air Force Base).

As of February 2007, findings from this ongoing study show that at least two different scales of historical shoreline erosion occur on Santa Rosa Island. The variation in shoreline retreat at the 1,500-meter-length scale is strongly coherent and out-of-phase with island width. Higher rates of erosion are associated with the narrow sections of the island that are inundated early in a storm and are characterized by a high concentration of shell lag and moisture following the storm. The narrow sections of the island will have stronger gradients in surge elevation, which would lead to the development of breaches. The small dunes that tend to redevelop in these areas lead to little loss of sediment to the shoreface during a storm, and most sediment deposited along the back barrier is in washover fans. These deposits are eroded by frontal winds (Stone et al., 2004) and are transported alongshore towards the cuspate headlands (Houser et al., 2007). Further study is required to ascertain the link between the cuspate headlands and the erosion of the washover fans.

Post Hurricane Erosion of Washover Fans

Researchers from the University of West Florida recently examined the suspended sediment transport and morphodynamics of a washover fan on the sound-side of Santa Rosa Island and found that the direction and magnitude of suspended sediment transport varies with the degree of local wave dissipation. While most of the erosion of the washover fan occurred during the first cold front following Hurricane Katrina, significant reworking of sediment was still observed during subsequent storms through spring 2006. The limited data set suggests that sediment is transported offshore during relatively weak storms, when the ratio of wave height to water depth is small, which promotes the development of an offshore-directed current along the upper shoreface. In contrast, waves tend to break along the seaward edge of the terrace leading to strong skewed accelerations and weak offshore currents. While cross-shore currents were important during the observed storm, the alongshore currents are equally strong despite the almost shore-perpendicular winds. Researchers conclude that with more oblique winds, transport will become increasingly directed alongshore, in the direction of the cuspate forelands. This suggests a link between the erosion of washover sediment and the development (or at least maintenance) of the cuspate forelands.

Post-Hurricane Dune Recovery on Santa Rosa Island

Field observations by investigators from the University of West Florida suggest that sediment transport from the narrow beachface and berm on Santa Rosa Island is limited by a lag of shells and gravel from the pre-Ivan road bed. As a consequence, sediment input to the dune is relatively minor with onshore winds, despite the presence of washover fans deposited during frontal storms in the swale behind the berm. The resulting sediment transport gradient across the seaward slope of the dune is more reflective of the expanding fetch than of topographic acceleration and the drag imposed by the sparse vegetation. In contrast, a larger sediment input to the dune during offshore winds is in response to the larger fetch across the washover terrace, despite the presence of a lag. Investigators conclude that post-hurricane dune recovery in this area is strongly dependent upon the deposition of washover sediment during frontal storms and the resulting development of a sand ramp through the swale. This will increase both the availability of sediment and the fetch for winds directly or obliquely onshore.

Preliminary evidence from a study by Brooke Saari (MS student, University of West Florida) suggests that the gradients in sediment transport and the associated change in island topography (dune growth) vary considerably alongshore in a manner that is consistent with the pre-storm morphology of the dunes and the impact level of the storm. Since the pre-storm morphology and impact to the dunes correspond to the width of the island and the location of the transverse ridges, investigators expect that the dune recovery is geologically forced.

Results from Petit Bois Island

University of West Florida investigators used lidar (light detecting and ranging) and bathymetric data to examine the morphological response of Petit Bois Island to Hurricane Katrina. Results suggest that the island experienced significant topographic change due to wave impact and inundation. However, the large surge levels and elevated wave energy caused the pre-storm dunes and ridges on the island to migrate landward in a manner similar to nearshore bars in the inner surf zone (Houser and Greenwood, 2007); the island did not express the normal storm impacts proposed by Sallenger (2000). The lack of significant elevation and bathymetric change is attributed to extreme surge levels, which would have covered the island, and an exponential increase in significant wave height, prohibiting the island from progressing through the impact regimes proposed by Sallenger (2000). The degree to which the island dune migrated landward as ridges is found to vary in response to the pre- and post-storm dune height and connectivity.

Sand Wars

During the scoping meeting, Ron Hoenstine (Florida Geological Survey) pointed out the significance of sand resources for beach nourishment. As resources become scarce, "sand wars" between Florida communities for compatible beach sand have begun. For instance, sand resources have been exhausted in the vicinity of Miami, Florida, and community leaders are looking to the Bahamas and other parts of Florida for beach-quality sand.

In order to be able to respond quickly after future storm events, the Florida Geological Survey is conducting seismic reconnaissance of sand resources in Florida waters. The limit of state waters is 3 miles (5 km) offshore; in the western part of Florida this limit extends to approximately 10 miles (16 km) offshore. Environmental assessments accompany reconnaissance studies.

Sea-Level Rise

Rising sea level is of great practical concern to the National Park Service because of the numerous impacts currently affecting and predicted to affect the more than 7,000 miles (11,263 km) of shorelines in the National Park System (Saunders et al., 2006). These impacts include inundation, erosion or land loss, loss of structures, loss of habitat, and loss of marine and terrestrial species (Toscano, 2004). Otvos (2004b, 2005d) provides an updated Holocene sea-level curve that is applicable to Gulf Islands National Seashore and vicinity. With respect to Gulf Islands National Seashore, scoping participants identified questions relating to sea-level rise: At what rate and when will the barrier islands be submerged? What is the NPS response?

According to Leatherman (1988), since the Atlantic and Gulf coastal plains are broad, gently sloping surfaces, a small rise in sea level results in a dramatic horizontal retreat of the land. For a barrier to maintain its existence during a given rise in sea level, it must migrate landward a distance that is two or three orders of magnitude greater than the value of the sea-level vertical rise. Along the U.S. East and Gulf coasts, the relative rise has averaged about 1 foot (0.3 m) per century, which would require a horizontal retreat of 100 to 1,000 feet (30–305 m) per century. The U.S. Geological Survey calculated a coastal vulnerability index (CVI) for the shoreface areas of the Gulf Coast (see http://pubs.usgs.gov/of/of00-179/ [accessed December 18, 2006]). The CVI is an equation used to quantify the vulnerability of a coastal area to sea-level rise and represents an attempt to quantitatively identify areas where effects of sea-level rise may be greatest. The index is meant to facilitate hazard assessments as a result of future sea-level change.

Of the approximately 90 miles (145 km) of mapped shoreline evaluated in Gulf Islands National Seashore (Pendleton et al., 2004), investigators classified 24% as being very highly vulnerable to future sea-level rise; 18% as highly vulnerable, 36% as moderately vulnerable, and 21% as having a low vulnerability. For Gulf Islands National Seashore, regional coastal slope and shoreline change were the principle variables determining vulnerability; wave height, tidal range, and geomorphology produced little to no variability in the coastal vulnerability index.

The coastal vulnerability index identified a section of Santa Rosa Island on the Gulf side, east of Fort Pickens, as highly vulnerable. This refers to a section of the island where a dune no longer exists, and where the back-barrier marsh is extremely narrow in comparison to neighboring areas (as seen on site in March 2003). Combined with hurricane damage from recent storms, sound-side erosion is probably causing this problem and setting the stage for a major island breach during a future hurricane. Such a breach would effectively separate and isolate the Fort Pickens area of the national seashore from the rest of Santa Rosa Island. The coastal vulnerability index does not extend to the sound side of the island, nor does it apply to the Gulf Breeze peninsula between Santa Rosa Sound and Pensacola Bay.

In contrast to the Florida sector, Mississippi barrier islands are not as well supplied with a source of new sediment from the east (no headlands) and each isolated island must recycle and conserve its own localized sand resources against sea-level rise and losses to storm events. Littoral drift annually transports 159,570 cubic yards (122,000 m^3) of sand to the west (Shabica et al., 1993). The USGS coastal vulnerability study flagged most of these islands as very high vulnerability areas, with only small sections assessed as low vulnerability. The downdrift (west) tip of West Ship Island is not vulnerable. Except for some shore retreat/back cutting during storms, western West Ship Island receives ample drift supply from the east, which corrects erosion. However, east West Ship and East Ship islands, and the former central island area between them, have suffered serious area losses in the past and recently during Hurricane Katrina, as did the eastern ends of Horn and Petit Bois islands (Otvos and Carter, 2007)

Shoreline Change

Shoreline changes have occurred in states bordering the Gulf of Mexico as a result of natural processes and human activities. The physical factors with the most influence on shoreline change are reductions in sediment supply, relative sea-level rise, and frequent storms (Morton, 2003). Critical human activities are sediment excavation, river modification, and coastal construction (Morton, 2003).

To assess changes in island geomorphology and provide data for park management, the National Park Service and the U.S. Geological Survey are currently analyzing shoreline change to better understand historical trends and short-term impacts and recovery to severe storm events. According to Hapke and Beavers (2006), over a 140-year period from the late 1800s to 2001, the average shoreline change rate was -0.98 feet (-0.3 m) per year at the Fort Pickens unit, Santa Rosa Island. Areas of historic erosion, reaching a maximum rate of -4.6 feet (-1.4 m) per year, correspond to areas that experienced overwash and road damage during the 2004 hurricane season. The shoreline erosion rate in the areas where the park road was heavily damaged doubled as a result of Hurricane Ivan, increasing to -9.2 feet (-2.8 m) per year. Additional post-storm monitoring of this section of the island will assess whether erosion rates stabilize. In addition, monitoring will help determine the best long-term management strategy for park infrastructure.

Major renourishment projects occurred on Perdido Key in 1985 and between 1989 and 1991. The erosion rates on the eastern end of Perdido Key before renourishment were between -1.0 and -9.0 feet (-0.3 and -2.7 m) per year. The shoreline change rates for Santa Rosa Island were much lower at 0.0 to -1.0 feet (0.0 to -0.3 m) per year; however, near the Fort Pickens area, the rates were 3.5 feet (1.1 m) per year near the inlet. On both sides of Pensacola Pass, random, unpredictable, large-scale changes have occurred (Foster et al., 1999).

Investigators determined the long-term land loss for the fortified mainland shores along the Mississippi Sound to be relatively low, as a result of extensive armoring and beach nourishment projects (Canis et al., 1985). However, the erosion of the Mississippi barrier islands is rapid, demonstrated by an average long-term rate of approximately -10 feet (-3.1 m) per year, which applies to 80% of the shoreline (Morton et al., 2004). The short-term average rate of 60% of the shoreline is greater at -19.0 feet (-5.8 m) per year. Shoreline retreat and land loss in the Mississippi barrier islands have been steadily accelerating in the past 160 years (Otvos and Carter, 2007). Thus, with major hurricanes in the future, East Ship Island may be approaching extinction within a few decades (Ervin Otvos, University of Southern Mississippi, written communication, February 4, 2007).

Tsunamis Potential

On February 10, 2006, a mid-plate earthquake of 5.2 preliminary magnitude occurred 160 miles (260 km) offshore from New Orleans in the Gulf of Mexico. The epicenter of a larger quake (6.0 preliminary magnitude), which followed on September 10, 2006, was located farther offshore. The second quake occurred two days before the scoping meeting at Gulf Islands National Seashore, and the geoscience-minded participants briefly discussed the earthquake and the potential for a tsunami to affect the national seashore in the future. Scoping participants surmised that an underwater landslide would be the cause of a tsunami that would affect Gulf Islands National Seashore. The landslide would produce a series of waves that would travel outward in all directions. Unlike Pacific shores, however, no cases of tsunamis have been documented for the Gulf of Mexico, either stemming from tectonic causes or sufficiently major landslides, which could take place along and behind the steep northern continental slope.

Tsunamis can originate hundreds or even thousands of miles away from coastal areas. Local geography may intensify the effect of a tsunami, inflicting severe flooding in low-lying coastal areas. Areas at greatest risk are less than 50 feet (15 m) above sea level and within one mile (1.6 km) of the shoreline. A diagram showing the epicenter of the earthquake that occurred on September 10, 2006, is available at http://wcatwc.arh.noaa.gov/message000561-01.htm (accessed December 18, 2006). Based on this earthquake's location and magnitude, a widespread damaging tsunami was not expected; however, some areas along the U.S. Atlantic, eastern Canadian, and Gulf of Mexico coasts may have experienced non-damaging sea-level changes.

According to the Texas Department of Public Safety at http://www.txdps.state.tx.us (accessed December 18, 2006) no authoritative estimates have been made of the extent of the risk that tsunamis hazards may pose to states with coastlines on the Gulf of Mexico. Moreover, no dedicated tsunami warning system presently exists for the Gulf of Mexico, but government agencies can be expected to disseminate warnings of potential threats caused by seismic and volcanic events through the Emergency Alert System and the news media. The U.S. Pacific Tsunami Detection and Warning System is being expanded to include the Caribbean, the Gulf of Mexico, and areas of the Atlantic that could affect the U.S. coast. The Caribbean Tsunami Monitoring System will include earthquake monitoring by the U.S. Geological Survey and tsunami monitoring by the National Oceanic and Atmospheric Administration (NOAA) (Daniel MacNamara, USGS National Earthquake Information Center, e-mail communication, November 21, 2006). By mid-2007, NOAA will deploy 32 new tsunami detection buoys for a more extensive tsunami warning system for the Caribbean, Gulf of Mexico, and Atlantic coasts (see http://pubs.usgs.gov/fs/2006/3012/ [accessed February 23, 2007).

Geologic Mapping for Gulf Islands National Seashore

During the scoping meeting Tim Connors (NPS Geologic Resources Division) showed some of the main features of the GRE Program's digital geologic maps, which reproduce all aspects of paper maps, including notes, legend, and cross sections, with the added benefit of being GIS compatible. The NPS GRE Geology–GIS Geodatabase Data Model incorporates the standards of digital map creation set for the GRE Program. Staff members digitize maps or convert digital data to the GRE digital geologic map model using ESRI

ArcMap software. Final digital, geologic map products include data in geodatabase, shapefile, and coverage format, layer files, FGDC-compliant metadata, and a Windows HelpFile that captures ancillary map data. Completed digital maps can be downloaded from http://science.nature.nps.gov/nrdata (accessed December 18, 2006).

Because the National Park Service has not established a standard for mapping National Park System units with coastal and marine (submerged) geologic resources, this scoping summary outlines a plan for developing a map product for use in resource management at Gulf Islands National Seashore. The proposed plan consists of four tasks:

1. Compilation and analysis of existing data
2. Field "mapping" of the geologic framework (including bathymetry and shoreface profiles) and surficial geology
3. GIS integration of items 1 and 2 into the NPS format for digital geologic maps
4. Modeling of barrier-island evolution and sediment transport

Various stakeholders and funding sources may be available to assist with the mapping plan (see "Stakeholders and Partners" and "Potential Funding Sources" sections).

Data Compilation

Existing data sets from numerous sources need to be compiled and analyzed in order to identify "gaps" to be filled during the field mapping portion of the project. "Gaps" include those areas of interest to park management for which no data or inadequate data exist. For Mississippi, park managers want map coverage for Cat, West Ship, East Ship, Horn, and Petit Bois islands on both the Gulf of Mexico and Mississippi Sound sides, as well as the Davis Bayou area. In addition, park managers would like existing data (no new mapping) for Dauphin Island off the coast of Alabama to be included in the final map product. The preferred scale is 1:10,000.

For Florida, park managers want the following areas on both the Gulf of Mexico and Santa Rosa Sound sides included in the map product: the Perdido Key portion of the national seashore; Perdido Key State Park, just west of the park boundary; Santa Rosa Island to Grayton Beach, including Okaloosa; the Naval Live Oaks area; and Fort Barrancas. The preferred scale is 1:10,000.

Park and GRD staffs are in the process of estimating funding and creating a position that would compile and analyze existing data. The position may be a term appointment or a Geoscientist-in-the-Parks (GIP). Monette Dalal, MS student at Kent State University in Ohio, is a potential candidate. In addition, the Gulf Coast Research Laboratory in Ocean Springs, Mississippi, may have a graduate student who could compile such data. Also, Lisa Robbins (Florida Shelf Habitat [FLaSH]) Map Project), has funded a student at the University of South Florida, working in Al Hine's lab, analyzing seismic data; this student may be able to assist with developing a geologic framework for Gulf Islands National Seashore. Graduate students from the University of West Florida and Georgia Institute of Technology may also provide a pool of candidates.

The following is a list of possible sources of data for the mapping project, which was compiled from the University of West Florida proposal (Houser and Fagherazzi, 2006), Jim Flocks' presentation (U.S. Geological Survey), and correspondence from Rebecca Beavers (NPS Geologic Resources Division) and Martha Segura (NPS Gulf Coast Network). In addition, Tim Connors (NPS Geologic Resources Division) presented maps from the Florida Geological Survey and U.S. Geological Survey for consideration during the scoping meeting.

- Barrier Island Comprehensive Monitoring Project—This project receives funding primarily from the Louisiana Department of Natural Resources; the U.S. Geological Survey provides some matching funds. The University of New Orleans, Department of Earth and Environmental Science, coordinates the project and serves as the liaison between the U.S. Geological Survey and the Louisiana Department of Natural Resources. In 2006 investigators surveyed 193 square miles (500 km^2) from Raccoon Island to the Chandeleur Islands. Contact: Jim Flocks (USGS) (see table 1).
- Coastal Classification Mapping Project (USGS)—Bob Morton and Russ Peterson published a coastal classification atlas for the Mississippi and Alabama shorelines of the Gulf Coast (USGS Open-File Report 2005-1151), which is available at http://pubs.usgs.gov/of/2005/1151/ (accessed December 18, 2006). *Note*: This 2005 publication reports the pre-Hurricane Katrina configuration. Additional information is available at http://coastal.er.usgs.gov/coastal-classification/ (accessed February 23, 2007).
- Florida Geological Survey—Morgan and Donoghue collected seismic data of the subbottom (sediments below the seafloor) 0.6–1.2 miles (1–2 km) from shore but missed a 650-foot- (200 m) wide swath along the coast for the Santa Rosa and Perdido Key portions of Gulf Islands National Seashore. The Florida Geological Survey also has map data of surficial and bedrock geology, oil and gas wells and infrastructure, paleontological resources, and sinkholes.
- Florida Shelf Habitat (FLaSH) Map Project (USGS)—Lisa Robbins, one of 15 representatives on the Florida Oceans Council, is the contact for this project. Robbins would be happy to work with partners on this project and may be able to provide some matching funds for shelf-habitat mapping efforts in Florida (Rebecca Beavers, GRD, written communication, September 19, 2006). Florida's Fish and Wildlife Research Institute is compiling data for the project's Web site at http://coastal.er.usgs.gov/flash/ (accessed December 18, 2006), though few high resolution bathymetry data are available for Florida.
- Hurricane and Extreme Storm Impact Studies (USGS)—The USGS Coastal and Marine Geology Program investigates the extent and causes of coastal impacts of hurricanes and extreme storms on the coasts of the United States. The contact for this project is Abby (Asbury) Sallenger. The overall objective of the program is to improve the ability to predict coastal change that results from severe storms. Such a capability will facilitate locating buildings and infrastructure away from coastal-change hazards (see http://coastal.er.usgs.gov/hurricanes/ [accessed December 18, 2006]).
- Integrated Remote Sensing and Modeling Group (USGS)
- Louisiana Sedimentary and Environmental Database (LASED)—This system contains a wide variety of data including bathymetry, sediment cores, seafloor change images, seismic-reflection profiles, and sidescan-sonar mosaics. The database also provides a permanent online digital data-archive system that holds information for dozens of research cruises. Currently restricted to Louisiana, LASED provides a template for future development of similar databases in other regions of the Gulf Coast, and a layer for geologic data from the coastal regions of Mississippi and Alabama is planned as part of the Northern Gulf Coast Ecosystem Change project. Further information on the LASED geo-database is available at http://coastal.er.usgs.gov/lased/ (accessed February 23, 2007).
- Minerals Management Service (MMS)–Florida Sand Management Working Group (Contact: Barry Drucker) and the USACE Gulf of Mexico Sand Management Working Group (Contact: Larry Parson)—These groups are composed of representatives from federal (MMS, USACE, and USGS) and state agencies (Florida Geological Survey [FGS], Florida Department of Environmental Protection [FDEP], and Florida Shore & Beach Preservation Association [FSBPA]), and private industry working together to develop a sediment management master plan to assist in beach nourishment, coastal restoration, and wetlands protection projects.
- Marine Aggregate Resources and Processes (Contact: Jeff Williams, USGS–Woods Hole)—An information-processing system for marine sediments (usSEABED) is part of this project. Collaborators of the project are USGS Coastal and Marine Geology Program, NOAA National Geophysical Data Center, and the Institute of Arctic and Alpine Research (INSTAAR). This project hosts a database of surficial sediments for the Gulf of Mexico at http://soundwaves.usgs.gov/2006/09/pubs.html (accessed December

18, 2006). Information about the usSEABED database is available at http://walrus.wr.usgs.gov/usseabed (accessed February 23, 2007).

- Mississippi Coastal Geology and Regional Marine Study—The Mississippi Office of Geology and the U.S. Geological Survey collaborated during the 1990s and gathered existing data for the Mississippi Sound under cooperative agreement 14-08-0001-A0827. Klaus Meyer-Ardent, who was a participant at the scoping meeting, was a collaborator on this project.
- National Assessment of Coastal Change Hazards (USGS)—Information available at http://coastal.er.usgs.gov/national-assessment/ (accessed February 23, 2007).
- National Assessment of Shoreline Change (USGS)—Data for this project includes information from both Mississippi and Florida and show the Mississippi islands narrowing and migrating over time. According to Bob Morton, land loss change is not tied to storms. The progradation of the St. Bernard delta exerts control over the Mississippi islands. More information is available at http://coastal.er.usgs.gov/shoreline-change/ (accessed February 23, 2007).
- National Oceanic and Atmospheric Administration (NOAA)—Another potential source of data (i.e., bathymetry and side-scan sonar) for the Gulf Islands in Mississippi is NOAA (Martha Segura, NPS Gulf Coast Network, e-mail correspondence, September 22, 2006).
- Northern Gulf of Mexico Science Plan (Coordinator: Dawn Lavoie)—Extending from Florida to Texas, this project is in the development phase and may provide substantial financial resources to understanding the dynamic geology and physical processes of this area. The earliest possible date for surveying (side-scan sonar and seismic) to begin is 2008.
- Prediction of Northern Gulf Coast Ecosystem Change and Hazard Susceptibility (Contact: John Brock, USGS–St. Petersburg)—In order to improve understanding of shoreline change, this project will provide an assessment of northern Gulf Coast climate and landscape evolution. The project is the USGS Coastal and Marine Geology Program's contribution to the USGS Gulf of Mexico Science Plan. The project area includes Gulf Islands National Seashore, and will provide a Holocene evolution and geologic characterization of the barrier islands. A synthesis of geologic knowledge is currently underway, which will identify areas where additional field surveys may be necessary. The project consists of the following tasks: (1) Holocene evolution of northern Gulf Coast climate, geomorphology, and ecosystem structure (Contacts: Dave Twichell, USGS–Woods Hole; Jim Flocks, USGS–St. Petersburg), (2) historical period evolution of the northern Gulf Coast landscape (Contact: Richard Poore USGS–St. Petersburg), (3) prediction of the 21st century northern Gulf Coast landscape and human community structure (Contact: Barbara Poore, USGS–St. Petersburg), and (4) prediction of the susceptibility of northern Gulf Coast ecosystems and communities to severe storms during the 21st century (Contact: John Brock, USGS–St. Petersburg).
- Reconnaissance Offshore Sand Search—Cooperation among the Florida Department of Environmental Protection, URS Corporation, Florida State University, and University of South Florida has resulted in a study of the coastal region of the Florida Panhandle. The data set includes more than 3,000 sand sample, 400 sediment cores, high resolution bathymetry, and more than 1,865 miles (3,000 km) of subbottom seismic lines.
- Submarine Ground-Water Discharge (Contacts: Peter Swarzenski and Chris Reich, USGS–St. Petersburg)—Information about the studies and methodologies of this program can be found at http://sofia.usgs.gov/publications/ofr/2004-1369/, http://sofia.usgs.gov/publications/fs/2004-3117/, and http://sofia.usgs.gov/publications/ofr/2004-1226/ (accessed February 23, 2007).
- Subsidence and Sea-Level Rise in southeastern Louisiana (USGS)
- University of Southern Mississippi, Coastal Sciences Department—An NPS grant currently provides funding for a post-hurricane landform and vegetation survey of the Mississippi portion of Gulf Islands National Seashore (Ervin Otvos, University of Southern Mississippi, e-mail communication, February 6, 2007).
- University of Southern Mississippi, Coastal Sciences Department, and Mississippi Office of Geology—Otvos (1981) used data from a network of closely spaced rotary core holes (penetrating much deeper than

vibracores) that showed detailed stratigraphic depositional facies from the entire Holocene sequence of the Mississippi-Alabama barriers and from Mississippi Sound transects. This information was critical in identifying the islands genetic background (see Otvos 1985a, 1986).

- University of West Florida—The Department of Environmental Studies is completing a series of studies, using lidar, which examine the morphological changes at Gulf Islands National Seashore during recent hurricane activity. In addition, university investigators are presently mapping the inner shelf bathymetry to examine the role of Hurricane Katrina within the context of longer term trends since 1857. Also, J. P. Morgan collected numerous vibracores from Santa Rosa Island during his tenure at the University of West Florida; the Department of Environmental Studies maintains these samples.
- West-Central Florida Coastal Studies (USGS)

Field Mapping

During the scoping process, park staff suggested that a currently existing proposal from the University of West Florida could serve as a starting point from which to develop a GRE mapping plan. Chris Houser, a participant at the scoping meeting, is the principal investigator of this proposal. In October 2006, a team of investigators and NPS staff submitted a revised proposal to the Project Management Information System (PMIS) for Natural Resources Protection Program (NRPP) funding. Though this proposal is apparently not moving forward for funding at this time, it is still in the PMIS system and could be resubmitted for NRPP funding again in the future (Linda York, NPS Southeastern Regional Office, written communication, February 6, 2007). In addition, Rebecca Beavers (NPS Geologic Resources Division) suggested that work by Stan Riggs and others could serve as a model for the mapping plan.

The following tasks are outlined in the NRPP proposal:

- Map nearshore bathymetry in order to locate and describe shoreface profiles, submarine headlands, hard bottom features, shoals, and other seafloor characteristics. This will involve the use of side-scan sonar and high-resolution seismic reflection to determine the underlying structure of the shallow (<100 m) nearshore sea bottom.
- Characterize the underlying strata and sediments along the east-west axis of the islands through vibracore. This includes the following tasks: (1) analyzing vibracore borings and (2) incorporating borings into existing GIS platforms.
- Characterize the underlying strata and sediments at regularly spaced transects perpendicular to the islands using vibracores from the inner shelf to the limit of wave and current transport within the sound. This includes the following tasks: (1) analyzing vibracore borings and (2) incorporating borings into existing GIS platforms describing the topography of the seashore.
- Map spatial and temporal distribution of historic inlets and breach corridors using existing aerial photographs in combination with the results from the vibracores.
- Include existing maps of terrestrial geomorphology of the barrier islands based on 2005 lidar images as a topographic baseline and updated through a combination of aerial photography and field checking.

In addition, field mapping would address data needs for documenting the sediment budget:

- Map current grain size and sorting on land and underwater in both the Florida and Mississippi sections of Gulf Islands National Seashore. This will involve both grab-sampling of sediments and in situ measurement to determine not only sands with similar provenance but also areas where sands are actively moving or more stable.
- Evaluate large-scale sediment movement and long-term trends using historical maps, T-sheets, lidar datasets, and existing bathymetric data.
- Determine short timescale fluxes using acoustic concentration profilers and laser in situ profilers, which includes (1) establishing a correlation curve between the laser in situ profilers (which are towed by boat

and yield a “snapshot” of sediment movement over a wide area) and the acoustic concentration profilers (which are stationary and can be left in place for up to a year, establishing a history of sediment movement in one place), (2) establishing a fair-weather “baseline” of sediment movement using the laser profilers, (3) monitoring sediment movement during and after important geologic events (e.g., extreme storms, minor storms, and coastal flooding) using the laser profilers to determine changes during these events from the baseline, and (4) deploying the acoustic profilers in geologically important regions (i.e., passes between islands, river mouths, and in front of barriers) to determine seasonal or event-related changes in sediment flux.

Geologic Framework

The geologic framework underlies the shoreface and the inner shelf and influences the physical processes operating on the shoreface system. According to Riggs et al. (1995), the geologic framework includes the following: (1) older stratigraphic units beneath and seaward of the shore, (2) stratigraphically controlled bathymetric features of the inner shelf, and (3) ancient drainage system—fluvial valleys filled with younger coastal sediments separated by large interfluve areas of older stratigraphic units. During times of lower sea level, the continental shelf is covered by a network of fluvial channels, which are flooded once sea level rises.

In this project, the shoreface system or profile will be incorporated into mapping of the geologic framework. The shoreface profile is indirectly a part of the geologic framework, but is usually directly influenced by the geologic framework (Linda York, NPS Southeast Regional Office, e-mail correspondence, September 29, 2006). The shoreface is that area along the shore just seaward of the low tide line (and always covered by water). The slope of the shoreface, the type and amount of sediments that are there, and other morphological characteristics are largely controlled (or at least greatly influenced) by the underlying geologic framework. Moreover, these characteristics along a shoreline will in turn influence the coastal processes in different areas (e.g., orientation of the shoreline or island, wave patterns, and rates of erosion). During scoping, the term “benthic habitat” was also used to describe this portion of the coastal environment.

Describing the slope, types of sediments (e.g., finer grained vs. coarser grained), and the underlying geology (e.g., old filled channel or older cemented layers in the shoreface) will help identify segments of the shoreline that are erosion “hot spot” and where future breaching or severe erosion might occur in the future (Linda York, NPS Southeast Regional Office, e-mail correspondence, September 29, 2006).

Surficial Geology

Atop the geologic framework and shoreface profile is the surficial geology, also called “geomorphic environment” during the scoping session. This subaerial portion is an expression of geologic features and processes at Gulf Island National Seashore. To complete this portion of the mapping project, investigators will use many tools, including lidar images, side-scan sonar, and aerial photographs.

The Mississippi Department of Environmental Quality includes the following surficial units on its maps, which may serve as a guide for developing the geologic map for Gulf Islands National Seashore:

- Coppice dune
- Coalesced coppice dune
- Irregular dune
- Hummock dune terrace
- Degraded dune
- Dune ridge
- Precipitation dune
- Artificial beach
- Uplands
- Perched beach
- Coastwise spit
- Bulkhead/seawall
- Recurved spit
- Washover flat
- Washover corridor
- Washover terrace
- Maritime forest
- Marsh
- Tidal flat
- Open marine water

- Pond/lake/lagoon
- Major tidal channel
- Erosional scarp
- Riprap
- Marina/harbor
- Breakwater
- Dredge spoil

GIS Integration

The University of West Florida and NRPP proposals address integrating seismic and vibracore data into the existing GIS platform used by the National Park Service. Sonar images of the bed will be integrated with seismic and vibracore data within an ArcMap GIS environment. The data from the subtidal and subaerial environments will also be incorporated into a GIS platform previously developed for the National Park Service, which has layers describing the following:

- Cultural/historical resources linked with PDF summaries on each area
- IKONOS satellite imagery
- IFSAR (interferometric synthetic aperture radar) data
- Lidar
- Records of cultural features including archaeological digs and shipwrecks
- National Geophysical Data Center (NGDC) coastal relief model
- Landsat records
- Turtle movement records
- Habitat analysis maps
- Suitability maps
- Endangered-species and areas-at-risk maps

Modeling

Modeling of barrier island development is part of the University of West Florida and NRPP proposals. The results of modeling will be extremely useful in developing the final GRE report. Modeling will inform the highest priority identified by park staff during the GRE scoping meeting—defining the sediment transfer and budget between islands. According to the NRPP proposal:

The evolution of Santa Rosa Island during the last 20,000 years will be investigated with a bidimensional numerical model known as BIT (barrier island transgression). The model is able to simulate, under appropriate simplifying hypotheses, the evolution of the barrier island and shelf profile at the geologic timescale. The model incorporates physical processes such as wave action (both normal and storm waves) and rate of sea-level rise; the shelf profile; and as many as six different stratigraphic units. The processes of erosion and deposition of distinct sediment units are schematized for different finite time steps. The model has already been applied to Sand Key near Tampa Bay, Florida.

Despite the limitations of simple models of barrier island evolution, these models can bridge the gap between the results of detailed sediment transport studies, often based on fluid mechanics theories, and conceptual geologic models. This is particularly true when both the timescale and the spatial scale of the phenomenon under analysis make scaling up of theories and models, developed for short-term coastal processes, unrealistic. The model provides a unique way to interpret the paleosurfaces observed in the sonar and seismic data and describes the relative importance of terrestrial, shelf, and shoreface processes to the geologic framework. The model results will show the stratigraphic evolution based on island displacement with rising sea level and provide a basis to assess the mechanisms in which the islands actually evolved.

Fagherazzi et al. (2004) introduces a model to predict the evolution and the degree of incision and deposition by fluvial channels on the continental shelf during sea-level cycles. Fluvial deposits have been observed in the stratigraphy for the Mississippi portion of Gulf Islands National Seashore, and fluvial entrenchment is responsible for considerable relief of the inner shelf and shoreface in Mississippi and Alabama. The model accounts for mass-wasting processes and fluvial sediment entrainment and transport. These phenomena are simulated on a grid that represents the morphology of the continental shelf and corresponding coastal plain. Simulation results show the strong influence of shelf morphology on establishing channel networks during sea-level lowstands. The model predicts the geometry and thickness of sediment deposits, which are of fundamental importance for the spatial development of the channel network. The model indicates that the detailed structure of sea-level oscillations has a strong influence upon sediment redistribution and channel development on the shelf.

Stakeholders and Partners

Stakeholders in the mapping effort may include Santa Rosa Island Authority, and the authorities of Pensacola Beach and Navarre Beach. Potential partners include the Florida Geological Survey, University of West Florida, NOAA, the U.S. Geological Survey, and the National Marine Fisheries Service (Essential Fish Habitat characterization). Taking advantage of current funding opportunities (see "Potential Funding Sources") is necessary while gathering and analyzing available data.

Potential Funding Sources

In addition to NPS funding, such as the Natural Resources Protection Program (NRPP), participants at the scoping meeting identified the Florida Ocean Council as a possible source of funding for mapping at Gulf Islands National Seashore. The governor of Florida appoints the members of the Oceans Council. The Department of Environmental Protection and the Department of Agriculture and Florida Wildlife are co-chairs of the council. The Florida Department of Environmental Quality, Coastal Aquatic Managed Areas Section, supports the council's activities. The Florida legislature passed a list of research priorities last year, but the governor vetoed the list as part of an effort to eliminate $500 million in projects. The Florida Ocean Council is more ambitious this year and is meeting to revisit last year's requests. In December 2006, Ron Hoenstine (Florida Geological Survey) will know what will be submitted to the legislature.

The Florida legislature meets in March and April. If passed by the legislature and approved by the governor, areas of interest will be better known; mapping may be a high priority. After legislature and governor approval, request for proposals for specific types of work can be issued. Partnering and leveraging will be very important. Proposals can cover multiple years, but only full commitment to one year of funds will be granted. The funding availability will be known by early May 2007 with funds available in July 2007. A request for proposals will likely be issued in May 2007.

At Ron Hoenstine's recommendation, Rebecca Beavers (NPS Geologic Resources Division) called Steven Wolfe at the Florida Department of Environmental Protection (DEP) in Tallahassee (850-245-2094, steven.wolfe@dep.state.fl.us) and asked to be placed on the mailing list for Ocean Council and marine mapping announcements. The Department of Defense has a partnership with the State of Florida and other southeastern states and federal agencies called SERPPAS (Southeast Region Partnership for Planning and Sustainability). Information about SERPPAS is available at http://wrrc.p2pays.org/serppas/index.asp (accessed December 18, 2006). The Florida Department of Environmental Protection is the lead agency for Florida in this partnership, and Steven Wolfe is Florida's representative on the SERPPAS mapping team. In summer 2006, the Department of Defense suggested marine-bioregion mapping as a potential SERPPAS project. In fall 2006, this project was adopted, the boundaries established, and a "mapping team" put into place to guide the effort (Steven Wolfe, DEP, e-mail correspondence, December 12, 2006). Northwest Florida (i.e., the waters off the Florida Panhandle) was one of 13 regions proposed for mapping; in the preliminary prioritization performed at a February 2007 workshop, this region was the second highest priority in the state (Steven Wolfe, DEP, e-mail correspondence, February 22, 2007).

Steven Wolfe and Lisa Robbins (USGS) coordinated a workshop (February 7–8, 2007) to discuss terminology, goals, initiate communications and awareness among mapping entities, and establish priorities for mapping. The workshop, which was sponsored by the Florida Department of Environmental Protection and the U.S. Geological Survey with SERPPAS support, focused on waters off Florida. However, SERPPAS used the workshop as a pilot by which it may decide how to proceed in gathering similar information in the non-Florida parts of the southeast region. Exactly how those subsequent steps will occur has not yet been decided (Steven Wolfe, DEP, e-mail correspondence, February 22, 2007). Coordinators are collecting presentations and products from the workshop to post on a Florida mapping Web site in March 2007 (Steven Wolfe, DEP, e-mail correspondence, February 22, 2007).

In addition, the USGS Northern Gulf of Mexico project will be a good source for collaboration. NPS staff, in particular Martha Segura and Rebecca Beavers, are working closely with John Brock, project coordinator, and Dawn Lavoie, USGS Gulf of Mexico coordinator, as this project develops (Rebecca Beavers, GRD, written communication, November 17, 2006).

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